

# Advanced Engine Study Program

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#### **FOREWORD**

This technical report presents the results of an Advanced Space Engine Study. The study was conducted by the Pratt & Whitney Government Engines & Space Propulsion Division of the United Technologies Corporation for the National Aeronautics and Space Administration, Lewis Research Center, under Contract NAS3-23858, Task Order D.4.

The study was initiated in November 1988 and completed in January 1990. Mr. Paul Richter was the NASA Task Order Manager. The effort at P&W was carried out under Mr. James R. Brown, Program Manager, and Mr. Arthur I. Masters, Engineering Manager. Other individuals providing significant contributions in the preparation of the report were Donald E. Galler, Todd F. Denman, and Ricky A. Schied — System Performance Analysis; James R. Black and Aaron R. Fierstein — Heat Transfer; Gale L. Clark — Pump Design; and Bruce R. Branstrom — Turbine Design.

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## SECTION I INTRODUCTION AND SUMMARY

#### INTRODUCTION

NASA mission studies have identified the future need for a new Space Transfer Vehicle (STV) Propulsion System. The new system is to be an oxygen/hydrogen expander cycle engine of 7,500 to 50,000 lbs thrust or more, and must achieve high performance via efficient combustion, high combustion pressure, and high area ratio exhaust nozzle expansion. The engine is likely to require wide versatility in terms of such characteristics as throttleability, operation over a wide range of mixture ratios, autogenous pressurization, and in-flight engine thermal conditioning and vehicle propellant settling. Firm engine requirements will include: long life, man-rating, cost effective reusability, space basing, and fault-tolerant operation.

A design and analysis study was conducted to provide advanced engine descriptions and parametric data for STVs. The study was based on an advanced oxygen/hydrogen engine in the 7,500 to 50,000 lbf thrust range. Emphasis was placed on defining requirements for high performance with engine systems capable of achieving reliable and versatile operation in a space environment. Engine system requirements and goals are listed in Table 1.

The study was divided into three technical tasks. In the first task several expander cycle variations were compared from the standpoint of their applicability to a new space engine. Parametric performance, weight and envelope data were then prepared for the selected cycles. Under the second task, the selected cycles were used to investigate requirements for wide range throttling (20:1) and high mixture ratio (O/F = 12.0) operation. The third task was to conduct reviews and coordinate performance of the work.

#### CYCLE COMPARISON STUDY

Four expander cycle variations were evaluated with respect to their applicability to an STV-type engine, i.e., the full-, or single-, expander cycle; the split-expander cycle; the dual-expander cycle; and the full-expander cycle with a regenerator. The four cycles were compared on the basis of: (1) maximum achievable chamber pressure, which translates to engine performance, weight, and envelope, (2) system complexity, i.e., number of components, severity of cycle condition, technology availability, and program risk (3) throttling capability, and (4) high mixture ratio operation.

The comparison of maximum achievable chamber pressure was based on technology which was judged to be readily available by the mid-1990s and included two thrust chamber cooling methods — copper chambers with milled channel construction and tubular copper chambers. The results are shown in Figure 1 for the tubular copper thrust chambers. Based on the assumption of equivalent technology, the full-expander cycle with regeneration was found to have the highest chamber pressure capability. The maximum pressure with the split-expander cycle was near that of the regenerator cycle at thrust levels above 25,000 lbs, but dropped off at low thrust. The reduced capability was due to cooling limits, not available power. The dual-expander cycle shows good chamber pressure capability at low thrust, but is the lowest of the four cycles over the range of this study. Copper tubular thrust chambers were shown to provide a significant improvement in achievable chamber pressure over milled channel chambers.

On the basis of system complexity, the full expander cycle has the fewest components, the least severe design requirements, and is the most proven. The extra heat exchangers and oxidizer environment in the oxidizer turbine make the dual-expander cycle clearly the most complex. The split-expander cycle and full-expander cycle with regeneration were judged to be equal in complexity and slightly more complex than the full-expander cycle.

The primary difference in throttling and high mixture ratio operation between the four cycles is in the ability to provide adequate thrust chamber cooling and acceptable turbine inlet temperatures over the range of

TABLE 1. — ENGINE SYSTEM REQUIREMENTS AND GOALS

| -lydrogen                           |
|-------------------------------------|
| Dxygen                              |
| f to 50,000 lbf (Study Range)       |
|                                     |
|                                     |
| gn point at full thrust)            |
| .0 (operating range at full thrust) |
|                                     |
| r                                   |
|                                     |
|                                     |
|                                     |
|                                     |
| h not more than one                 |
| le/retractable section              |
| regen section to 1200 (Study Range  |
|                                     |
|                                     |
|                                     |
|                                     |
| /lbm at full thrust                 |
| /lbm at full thrust                 |
| Rated                               |
| st Compatible                       |
| ased                                |
| rts/20 Hours Operation (Goal)       |
| ts/4 Hours Operation (Goal)         |
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conditions required. The split expander cycle was found to have a significant advantage over other cycles for throttled and high mixture ratio operation.

On the basis of this comparison, the split expander and full expander cycle were selected as the cycles to be used for preparation of the parametric data. These data are presented in Appendix A of this report. The split expander cycle was selected as the baseline cycle for the throttling and high mixture ratio operation study. Secondary consideration was given to throttling the full expander cycle with regeneration.

#### THROTTLING AND HIGH MIXTURE RATIO OPERATION

The basic requirements for wide range throttling and high mixture ratio operation are: (1) achievement of high combustion efficiency over a wide thrust and mixture ratio range without excessive system pressure drop and complexity, (2) the ability to adequately cool the thrust chamber over the wide range of conditions required, (3) achievement of wide range control without undue control system complexity, and (4) pump flow stability and avoidance of turbine flow separation at low flowrates.

A number of design features were identified for meeting these requirements; they consisted of:

- Dual-orifice injection to provide acceptable pressure drop and high combustion efficiency over the wide range of fuel and oxidizer flows required (Figure 2)
- Use of the split-expander cycle to provide extra cooling capability for off-design operation
- Novel control schemes to provide increased cooling capacity at off-design conditions
- · Inducer-interstage struts and flow recirculation to provide off-design point pump stability
- Use of the split-expander cycle to reduce the turbine flow variation from full thrust to minimum thrust and, thereby, inhibit turbine flow separation at low thrust.

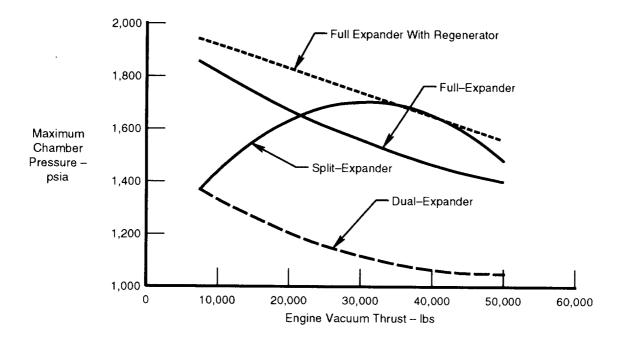


Figure 1. Comparison of Achievable Chamber Pressure for Four Cycles Using Tubular Copper Thrust Chambers

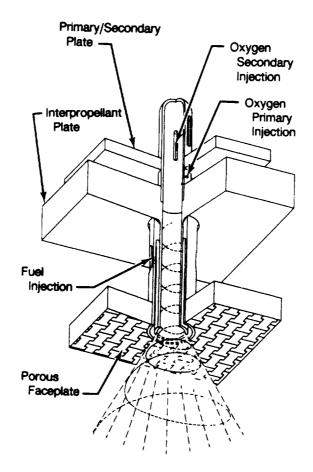


Figure 2. Dual-Orifice Injection

## SECTION II DESIGN AND PARAMETRIC ANALYSIS

#### **EXPANDER CYCLE COMPARISON**

The high-performance, oxygen-hydrogen expander cycle engine has been selected by NASA as the baseline propulsion system for the Space Transfer Vehicle (STV). As a part of this study, a comparison of four expander cycle variations: the full-expander, split-expander, dual-expander, and full-expander with regeneration was conducted. Study results have provided advanced engine descriptions and parametric data for NASA's STV contractors.

In preparing these data, a technology level consistent with the early-to-mid 1990s was established as a baseline and is described below. The attainment of a given chamber pressure in an expander cycle engine is highly dependent upon this assumed technology level as well as the degree to which the cycle is optimized. Definition of the technology level for any study is always subjective. Although some assumptions may be revised as technology develops, moderate changes are not expected to compromise the validity of the cycle comparison.

#### **Baseline Engine Parameters**

#### (1) Heat Transfer

- Milled channel copper chambers and tubular copper chambers
- Haynes 230 tubular nozzles for high material strength and high-temperature operation
- Regenerative-cooling to an area ratio of 210 to 1 for the full- and split-expander
- Regenerative-cooling to an area ratio of 400 to 1 for the dual-expander
- Maximum thrust chamber wall temperature of 1460°R.

#### (2) Pumps

- Fuel pump bearing bore diameter  $\times$  speed (DN) of 3.0  $\times$  10<sup>6</sup> rpm-mm
- Maximum pump tip speed of 2100 ft/sec
- Shrouded impellers.

#### (3) Turbines

- Back-to-back vaneless main turbines (except for dual-expander cycle)
- Maximum turbine tip speed of 2000 ft/sec
- Shrouded turbine blades.

Two thrust chamber cooling concepts were used in the baseline study: conventional milled channel copper thrust chambers and tubular copper thrust chambers. The tubular chamber provides an estimated 18 percent heat transfer chamber enhancement over the grooved chamber due to the increased hot wall surface area.

The pump bearing DN limit (product of diameter and speed in rpm-mm) was set at 3.0 million for the hydrogen turbopump and 1.4 million for the oxygen turbopump. Based on Pratt & Whitney's (P&W) demonstrated capability in the Space Shuttle Main Engine Alternate Turbopump Design and XLR-129 high-pressure engine, current DN limits are 2.4 million for ball bearings and 2.7 million for roller bearings in hydrogen and 1.4 million for bearings in oxygen. Previous P&W studies have indicated that 3.0 million DN for hydrogen is achievable with modest development. Although higher effective DNs are possible with hydrostatic bearings, higher speeds

complicate the pump design and drive the turbine toward partial admission (lower efficiency). The effect of turbopump speed was evaluated independently at 25,000-pounds thrust in the full-expander cycle.

Vaneless back-to-back, oxygen-hydrogen turbopumps are the baseline design for all cycles except the dual-expander cycle. Back-to-back turbines must operate with a single turbine drive and could not be applied to the dual-expander cycle. A discussion of each of the engine cycles and some component evaluations, which were also conducted, is contained in the following sections.

#### **Turbopump Configurations**

High turbopump efficiency is an important requirement for attaining high chamber pressure. One important issue is partial-admission versus full-admission turbines. The RL10 expander cycle engine initially had a partial admission turbine (approximately 120° admission), however, beginning with the RL10A3-3, the RL10 has used a full-admission turbine with a total-to-static efficiency of over 80 percent. A parameter used in turbine design, specific speed, illustrates the maximum obtainable efficiency and the optimum type of turbine. Figure 3 presents a specific speed efficiency curve. The STV cycle requires a high specific speed and a 2-stage, full-admission configuration to provide high turbine efficiencies.

Another issue investigated was turbine configuration. Back-to-back, counter-rotating, oxygen-hydrogen turbopumps were selected for the parametric study on the basis of their high turbine efficiency and compact packaging. A schematic of the concept is shown in Configuration A of Figure 4. Such configurations are not unique; they have been used for some time in gas turbine turbofan engines, but have not as yet been used in rocket engine turbomachinery. The configuration eliminates turbine-to-turbine pressure drop and decreases the inlet and exit guide vane losses. The configuration also provides a weight reduction by eliminating one turbine housing and inter-turbine ducting.

During independent component design studies conducted by P&W, analysis indicated possible rotor dynamic instabilities with some fuel pump configurations. Development of suitable damping techniques appears practical, but an alternative approach is use of a split rotor fuel pump driven by back-to-back turbines as shown in Configuration B of Figure 4. This configuration provides much shorter fuel turbopump shaft length for improved rotor dynamics at the expense of some of the weight and performance advantages of Configuration A.

#### Full-Expander Cycle

In the full-expander cycle, depicted in simplified form in Figure 5, fuel is pumped to a high pressure and used to cool the chamber and nozzle assembly and drive the turbopumps. The gaseous fuel is then injected into the main chamber to mix and burn with the liquid oxygen.

An advantage of any expander cycle engine is the relatively benign turbine environment compared to the staged combustion or gas generator cycles. The expander cycle also has lower turbopump discharge pressure requirements than the staged combustion cycle and higher performance than the gas generator. An expander cycle engine is accepted as a simpler, safer, more reliable propulsion system, having fewer failure modes than other cycles. The expander engine, of which the RL10 is an example, is a flight-proven concept.

The full-expander cycle relies on heat transferred from the chamber and nozzle to provide the energy required by the turbopumps. At low design thrust levels, the energy available in the cycle is sufficient to provide high chamber pressure levels. However, as design thrust increases the maximum achievable chamber pressure declines, as shown in Figure 6 for both copper tubes and milled channel copper chambers. Above an engine design thrust of 35,000 pounds, full-expander cycle engine chamber pressures are limited to just under 1500 psia based on the assumed technology level.

Throttling the full-expander cycle through the desired 20 to 1 range presents some difficult design challenges. Using the entire fuel flow for cooling, as thrust levels decrease, the coolant exit temperatures increase. High mixture ratio operation also presents a cooling problem for the full-expander cycle. The reduced fuel flow at the higher mixture ratios increases the chamber wall temperatures, reducing the chamber design life. These limitations can be partially offset by reducing combustor length, use of overcooling at the design point, or bypassing part of the flow at the design point and using all of the flow at off-design. However, these approaches introduce additional system complexity and cycle losses.

Overall, the full-expander cycle meets STV propulsion system requirements, but cooling requirements for throttling and high mixture ratio operation would either limit operation in this regime, require cycle compromises, or require added control provisions.

#### Split-Expander Cycle

In the split-expander cycle, shown schematically in Figure 7, a portion of the fuel bypasses the chamber and nozzle coolant passages and most of the turbomachinery. The split-expander retains the advantages of the full-expander discussed earlier and offers an additional benefit. With approximately half of the fuel flow routed from the 1st-stage pump discharge directly to the injector, the turbopump horsepower requirements for the split-expander cycle in a typical STV cycle are decreased by approximately 15 to 25 percent.

The energy available in the split-expander cycle is the same as the full-expander cycle for a given thrust and chamber pressure level. However, since the horsepower requirements of the turbopumps are less, the split-expander cycle can achieve higher chamber pressure levels at the same technology level. As shown in Figure 8, the split-expander cycle with a tubular copper chamber can achieve engine chamber pressures above 1500 psi at engine thrust levels of 12,000 to over 50,000 pounds. The maximum chamber pressure is approximately 150 psi higher with tubular chambers than milled channel chambers.

At thrust levels below 25,000 pounds, the maximum chamber pressure with the split-expander begins to drop. This decline is due to thrust chamber cooling requirements rather than cycle limitations. The decline could be avoided by reducing the fraction of cooling jacket bypass flow, however, significant reduction in the design point bypass flow would reduce the inherent advantages of the split-expander for off-design operation.

The ability to regulate chamber and nozzle coolant flow during engine throttling and high mixture ratio operation is an important benefit of the split-expander cycle. Because of the reduced coolant flow at full thrust, the coolant exit temperature of the split-expander is higher than the full-expander. As will be discussed later, the coolant exit temperature of the full-expander cycle rises as the engine is throttled. By using the split-expander jacket bypass valve (JBV) to increase the percent of coolant flow, the coolant exit temperature can be decreased up to a point during throttling. At some fraction of rated power, 30 percent in the case studied, the JBV is completely closed and the cycle operates like a full-expander. However, because the coolant passages for the split-expander are designed for a lower flow at rated power, the combustor wall stabilizes at a lower temperature during deep throttling, as shown in Figure 9. The full-expander curve shown in that figure is for a case that has not been optimized for cooling at throttled conditions. Lower temperatures can be obtained, but not without some compromise to the design point or increase in control system complexity.

High mixture ratio operation is also enhanced with the split-expander cycle. Using the JBV to increase the percent of coolant flow, the split-expander cycle is able to operate at higher mixture ratio levels with a lower combustor wall temperature. Figure 10 shows the cooler copper tube wall temperature attained with the split-expander cycle compared to the full-expander cycle. The difference in wall temperatures at the design point is because the data are for a throttled 1000 psia condition. For a thrust chamber that has been designed at an O/F of 6.0, 1000 psia is the highest chamber pressure that can be achieved while limiting the maximum hot wall temperature in the chamber to 1060°R (the blanching limit).

The full-expander cycle wall temperatures, which were shown in Figure 10, do not represent an optimized cooling scheme for high mixture ratio operation. This optimization cannot be accomplished, however, without significant cycle penalties at normal operation. Low wall temperatures are essential at high mixture ratio operation. The maximum wall temperature range for prevention of copper oxidation is 1060 to 1260°R without coatings. Use of coatings could reduce the wall temperature, but reliable coatings are not currently available and any coating will reduce the overall heat transfer and the available cycle power.

The split-expander cycle is an untested concept, but is based on fully understood fluid dynamic and thermodynamic principles. The split-expander cycle offers an attractive alternative to the full-expander cycle, meeting STV requirements over the desired thrust range, and greatly simplifying throttling and high mixture ratio operation.

#### **Dual-Expander Cycle**

Another variation of the expander cycle is the dual-expander cycle shown in Figure 11. The dual-expander cycle uses all the fuel flow to cool the chamber and drive the fuel turbopump. Oxygen is vaporized in the nozzle or an auxiliary heat exchanger and subsequently used to power the oxidizer turbopump. This cycle offers several advantages over both the full- and split-expander cycles. The oxygen turbopump does not require a special interpropellant seal package between the pump and turbine sections. The availability of gaseous oxygen at all thrust levels, simplifies the task of maintaining combustion stability during throttling. Separate turbine drive fluids simplify mixture ratio control, but add complexity to transient control.

For a given thrust and chamber pressure level, the energy available to the dual-expander cycle is the same as both the full- and the split-expander cycles. The turbopump horsepower requirements and the fuel pressure level are comparable to the full-expander. Because oxygen is less efficient as a turbine working fluid, and there is less flexibility in the split in turbine available energy, the dual-expander cycle is more pressure limited than the other cycles. Figure 12 shows the maximum chamber pressure attainable with the dual-expander cycle for both copper tubular and milled channel combustion chambers.

Above an engine thrust level of approximately 20,000 pounds, the dual-expander cycle cannot achieve chamber pressures above 1200 psia without use of regenerators or internal heat exchangers to provide additional energy to the cycle. While regeneration is possible, the achievable pressure would always be lower than with the same enhancements in a full-expander cycle except at low thrust (below 7500 pounds). At low thrust, expander cycles are limited by the hydrogen temperature out of the cooling jacket; allowing the oxygen to absorb a portion of the energy increases the total energy available within the temperature limit.

Using liquid oxygen to cool the nozzle also provides a source of gaseous oxygen to supply tank pressurant and promote combustion stability during deep throttling, negating the need for a variable area injector or a separate heat exchanger. However, experience has shown that achieving good mixing with gaseous fuel and gaseous oxidizer over a wide range of conditions is difficult, and combustion efficiency may suffer at throttled or high mixture ratio conditions.

Like the split-expander cycle, the dual-expander cycle is an untested concept. The dual-expander cycle differences from the proven full-expander cycle also are based on understood fundamental fluid dynamics and thermodynamics. Technology questions, such as turbine material characterization in gaseous oxygen and control during deep throttling and high mixture ratio operation, need to be addressed. Despite its pressure limits at moderate thrust and more complex operation compared to other expander cycles, the dual-expander remains a candidate for the STV, but primarily at low design thrust levels.

#### Regenerators and Enhanced Heat Transfer

A higher chamber pressure at higher thrust levels can be achieved through use of a regenerator or enhanced thrust chamber heat transfer in the full-expander and dual-expander cycles. The split-expander cycle can also benefit from enhanced heat transfer, but the lower chamber coolant flows do not provide adequate cooling when greatly enhanced heat transfer is used below 50,000-pounds thrust. The function of a regenerator is to increase the available turbopump power by recovering heat downstream of the turbines and using it to preheat the fuel before cooling the thrust chamber (Figure 13). Enhanced chamber heat transfer increases the available power to the turbines and can be achieved by using finned cooling tubes and ribbed chamber walls.

The upper limit chamber pressure for the full-expander cycle with regeneration is shown in Figure 14. The enhancement of the full-expander cycle with the addition of a regenerator, provides a significant increase in chamber pressure over the entire thrust range.

#### Cycle Selection

Figure 15 compares the four cycles studied on the basis of copper tubular thrust chamber construction. Figure 16 shows the same comparison using a milled channel copper chamber instead of tubular copper chambers. The full-expander cycle with regeneration produces higher chamber pressure levels, but the higher coolant temperature at the design point aggravates the already difficult job of cooling at throttled or high mixture ratio operation. Enhanced chamber heat transfer accomplishes the same results, but also raises the same concerns. Bypassing the regenerator at off-design conditions partially alleviates this problem.

On the basis of this comparison, the full-expander cycle with regeneration was judged to have the highest chamber pressure capability over the range of thrust considered. The capabilities of the split-expander cycle and full-expander cycle without regeneration were only slightly lower over most of the thrust range. The split-expander cycle was found to have unique advantages for throttled and off-design operation. The full-expander cycle with regeneration and the split-expander cycle were therefore selected as the cycles for developing the parametric data. The split-expander cycle was selected as the baseline for the throttling and high mixture ratio evaluation and the full-expander cycle with regeneration was given secondary consideration.

#### PARAMETRIC DATA

Engine parametric performance envelope and weight data were generated over the range of design point parameters studied (Table 2). The data are presented in graphical form in Appendix A. All data are for an oxidizer/fuel (O/F) ratio of 6.0.

TABLE 2. — ADVANCED ENGINE STUDY RANGE OF DESIGN POINT PARAMETERS

| Vacuum Thrust    | 7500 to 50,000 lbf            |
|------------------|-------------------------------|
| Chamber Pressure | 1000 psia to cycle limit      |
| Expansion Ratio  | Regenerative terminus to 1200 |

The upper limit chamber pressures presented in the "cycle selection" section ranged from 1040 to 1940 psia for the various cycles and thrust levels investigated. These limits are not absolute, but rather are relative limits based upon the assumed technology level chosen for this study. Chamber pressures above 2000 psia appear possible for most cycles at most thrust levels (refer to the "Higher Chamber Pressure Requirements" section). However, an upper limit of 2000 psia was selected for developing the parametric data. The following paragraphs describe the methodology used to produce the parametric data.

#### Performance

In calculating the predicted impulse, an ideal impulse was calculated, and then efficiencies were applied to the ideal impulse to account for various losses. These losses include energy release losses, kinetic losses, divergence losses, and boundary-layer losses.

The ideal predicted impulse was calculated with the NASA one-dimensional chemical equilibrium computer code (ODE) analysis using engine inlet fluid enthalpies. For this analysis, an adiabatic assumption was employed with the control volume encompassing the engine. The propellants enter the control volume at the engine inlet and exit the control volume at the nozzle exit plane. The energy release losses are accounted for by applying a combustion efficiency to the ideal impulse. For this study, a constant combustion efficiency of 0.992 was used which is based on performance expected with tangential swirl injectors. The remaining losses are accounted for by applying a nozzle efficiency to the impulse that has been corrected for energy release losses. For this study, a constant nozzle efficiency of 0.982 was used which is based on a maximum payload truncated bell nozzle.

A comparison was made between the method of performance prediction used in this study and experimental data presented in Table 3 (ref. 1). To make a valid comparison between the predicted and measured performance a few assumptions were made. First, the combustion efficiency ( $\eta C^*$ ) that was calculated from the experimental results was used in calculating the predicted performance rather than the constant combustion efficiency that was used in the study.

Second, typical cryogenic engine inlet propellant conditions were used to calculate the ideal specific impulse instead of using the measured injector inlet conditions (ref. 1). The second assumption was made so as to maintain the validity of the adiabatic assumption that was used in this study. During the experimental performance measurements, the propellants were not maintained at cryogenic conditions, but were heated to ambient temperature by the atmosphere. Also, as the propellants were combusted and expanded, heat was removed by the water jacket that surrounded the throat region and the heat retaining capacity of the metal. The ambient heat addition to, and the water jacket heat removal from, the propellants tend to offset one another, thus validating the adiabatic assumption.

As shown in Figure 17, the comparison shows best agreement around an O/F of 5.0 for the 1030 to 1 area ratio and best agreement around an O/F of 4.0 for the 428 to 1 area ratio. The difference between the predicted and experimental performance at the lower mixture ratios is probably due to the reduction in heat flux at lower mixture ratios while the ambient heat addition remains constant.

The chamber pressure levels from the experimental cases are much lower than those investigated in this study. The study (ref. 1) indicated that a laminar boundary layer assumption showed the best agreement with the experimental data. However, subsequent studies by NASA Lewis (ref. 2) indicate that for higher chamber pressure levels (360 to 2600 psia) a transitional boundary layer occurs. Although no performance data were presented, the transitional boundary layer would probably be detrimental to performance.

The parametric analyses show that thrust level has no effect on vacuum specific impulse while chamber pressure has very little effect, i.e., less than 1 second increase in going from a chamber pressure of 1000 psia to 2000 psia (Figure 18). Area ratio is the biggest driver of specific impulse. An area ratio above 900 would be required to achieve a 480 sec vacuum  $I_{sp}$  based on the current data.

TABLE 3. — COMPARISON OF P&W PREDICTED PERFORMANCE  $(I_{\rm spc})^{(1)}$  WITH MEASURED PERFORMANCE  $(I_{\rm spm})$  FOR THE NASA LEWIS 1030 TO 1 AREA RATIO NOZZLE (REF. 1)

| Reading | $\Lambda R$ | FVAC  | PC    | O/F  | $I_{spc}$ | $I_{spm}$ | $I_{spe}/I_{spm}$ |
|---------|-------------|-------|-------|------|-----------|-----------|-------------------|
| 112     | 1030.       | 544.4 | 360.0 | 3.84 | 456.1     | 468.9     | 0.973             |
| 113     | 1030.       | 541.6 | 356.9 | 4.36 | 457.7     | 460.4     | 0.994             |
| 114     | 1030.       | 552.3 | 360.9 | 5.08 | 459.2     | 451.9     | 1.016             |
| 115     | 1030.       | 550.4 | 355.3 | 5.49 | 458.6     | 449.7     | 1.020             |
| 117     | 1030.       | 531.5 | 356.2 | 3.19 | 451.8     | 473.4     | 0.954             |
| 120     | 1030.       | 546.1 | 355.2 | 4.30 | 457.7     | 466.1     | 0.982             |
| 121     | 1030.       | 552.9 | 360.0 | 4.11 | 457.7     | 473.6     | 0.966             |
| 123     | 1030.       | 534.3 | 355.2 | 3.19 | 451.8     | 481.1     | 0.939             |
| 124     | 1030.       | 536.4 | 361.4 | 2.78 | 447.4     | 481.3     | 0.929             |
| 125     | 1030.       | 541.0 | 354.0 | 3.74 | 455.6     | 477.8     | 0.953             |
| 136     | 428.        | 500.9 | 345.6 | 3.04 | 446.7     | 462.3     | 0.966             |
| 137     | 428.        | 531.6 | 356.8 | 4.29 | 453.3     | 452.6     | 1.002             |

Notes:

#### **Engine Envelope**

Engine overall lengths and exit diameters were calculated over the range of specified operating conditions. The length of the engine is from the gimbal mount to the nozzle exit plane and consists of three separate lengths. The first length is the distance from the engine gimbal mount to the injector face. This was estimated from layouts of engines of comparable thrust. The length of the combustion chamber, the second length, was held constant at 15 inches. The remainder of the engine length is the distance from the throat to the nozzle exit plane. A maximum payload bell nozzle contour was generated for the chamber pressures, thrust levels, and nozzle expansion ratios of the parametric study. The engine diameter is the exit diameter of the nozzle and is a function of the thrust level, chamber pressure, and expansion ratio.

#### Weight

Parametric engine weights were generated over the range of specified operating conditions. Historical thrust/weight data were used to estimate these weights with adjustments being made for size, cycle, material, and technology differences. These adjustments included nozzle weights which were calculated as a function of nozzle surface areas. The difference in weight between the split-expander cycle and the full-expander cycle with a regenerator were accounted for by adding or removing components. Analysis of the results, given in Appendix A, show a slight weight advantage for the split-expander cycle when compared to the full-expander cycle with regenerator.

#### **Nozzle Contour Trade-off**

The maximum payload bell nozzle contour, used throughout the parametric study, is a rather long nozzle that is used to attain high specific impulse. A sensitivity study was conducted to calculate the effect of nozzle contour on the trade-off of length and weight with performance. Nozzle contours from a minimum length to a maximum performance were examined for a chamber pressure of 1500 psia. The results are presented in Figures

 $<sup>^{(1)}</sup>$ I<sub>spc</sub> was calculated using one-dimensional equilibrium (with Engine Inlet Enthalpies), a constant nozzle efficiency (0.982), and the experimentally determined  $\eta C^*$ .

19 and 20 for the nozzle expansion ratio range of interest and show that going to a shorter nozzle can decrease engine weight by up to 12 percent for a high area ratio (1200 to 1) engine while dropping performance only approximately 1.0 second. However, for a relatively low area ratio (210 to 1) engine, performance decrease by almost 3 seconds when a minimum length nozzle contour is used while engine weight drops by only 3.5 percent.

### HIGHER CHAMBER PRESSURE REQUIREMENTS

The upper limit chamber pressures, discussed in the "cycle selection" section, were based on rather conservative assumptions of mid-1990s technology. Selection of the technology level for the cycle comparison was driven by these considerations:

- There appears to be little increase in specific impulse or system performance at chamber pressures above 1000 to 1500 psia.
- Not pushing the system design and associated technology levels to extreme limits provides margin for system flexibility, thereby simplifying throttling and high mixture ratio operation.
- Not pushing system design and technology levels to extreme limits reduces development difficulty (program risk) and helps ensure a high level of reliability.

Higher pressures are possible and may, under some circumstances, be worth the additional complication. A system sensitivity study was conducted to determine which of the cycle parameters in the original study most significantly limited chamber pressure and to show how modifying these variables could extend chamber pressure limits.

The cycle parameters used in the sensitivity study are listed in Table 4. As appropriate, the parameter sensitivity was investigated for both the split-expander cycle and full-expander cycle with regeneration.

TABLE 4. — APPROACHES TO HIGHER CYCLE CHAMBER PRESSURE

| Cycle Parameter Improvement            | Cycle  | Means of Achieving<br>Improvement                                  |
|--|--|--|
| Higher Pump Efficiency                 | Full-Expander With Regenerator<br>Split-Expander | Higher Pump Speed, Reduced Pump<br>Leakage                         |
| Higher Turbine Efficiency              | Full-Expander With Regenerator<br>Split-Expander | Higher Turbine Speed, Reduced Tip<br>Leakage                       |
| Higher Turbine Pressure Ratio          | Full-Expander With Regenerator<br>Split-Expander | Higher Pump Discharge Pressure                                     |
| Coolant Jacket Bypass Flow             | Split-Expander                                   | Increase Bypass Flow to Obtain<br>Higher Turbine Inlet Temperature |
| Regenerator Effectiveness              | Full-Expander With Regenerator                   | Larger, More Effective Regenerator                                 |
| Increased Thrust Chamber Heat Transfer | Full-Expander With Regenerator<br>Split-Expander | Tubular Chamber,<br>Increased Thrust Chamber Length                |

The effect of pump efficiency on maximum achievable pressure is shown in Figures 21 and 22 for the two cycles. For the split-expander cycle, an increase of 5 percent in fuel and oxidizer pump efficiency over the baseline cycle pump efficiencies (approximately 65 percent for the fuel pump and 75 percent for the oxidizer

pump) produces an increase of 150 psi in chamber pressure if all other cycle variables are held constant. Fuel pump efficiency improvements could be achieved by developing hydrostatic bearings to operate well above the baseline cycle turbopump speed (125,000 rpm for the fuel pump) or by reducing internal pump leakage below current state-of-the-art projections. For the full-expander cycle with regeneration, a 5 percent increase in pump efficiency provides a 170 psi increase in chamber pressure.

Figures 23 and 24 show the effect of increases in turbine efficiency on chamber pressure. A 5 percent increase in fuel and oxidizer turbine efficiency over the baseline values of 80 to 85 percent produces an 85 psi chamber pressure increase for the slit expander cycle and a 95 psi increase in the full-expander cycle with regeneration.

All of the cycle studies prepared under the study have been based on a turbine pressure ratio of 2.1. Pratt & Whitney experience has shown that a pressure ratio of 2.1 produces a chamber pressure that is near, but slightly below the maximum that can be achieved. However, higher turbine pressure ratios produce only slightly higher chamber pressures at the expense of a very high head rise and discharge pressure requirement on the pump. This trend is shown in Figures 25a and 25b. For the full-expander cycle with regeneration, increasing the turbine pressure ratio to 2.4 increases chamber pressure by only 90 psi, while requiring an increase in pump discharge pressure of 1000 psi. Similarly, for the split-expander cycle, where the maximum chamber pressure is achieved at a turbine pressure ratio of 2.6 the chamber pressure is increased by only 120 psi over the reference value. Yet the balanced cycle at the pressure ratio of 2.6 requires a large increase in fuel pump discharge pressure to 6600 psia compared to the reference pump discharge pressure of 5100 psia.

The split-expander cycle has a unique variable that can be optimized for maximum pressure, i.e., the fraction of the fuel that bypasses the cooling jacket and turbines. All of the unthrottled split expander cycles prepared under this study have been based on 50 percent bypass flow. At low thrust (below approximately 20,000 pounds), the optimum bypass flow for maximum chamber pressure is below 50 percent; however, 50 percent was used as a minimum in the split-expander cycle to provide flexibility for cooling with throttling or high mixture ratio operation. As shown in Figure 26, increasing the jacket bypass flow at 25,000 pounds of thrust would produce a small increase in maximum chamber pressure at the expense of a significant increase in turbine inlet temperature.

In the full-expander cycle with a regenerator, the regenerator heat transfer effectiveness is a design variable that affects available power. A relatively low effectiveness was used in the cycle comparison study because of cooling limitation at low design point thrust and problems associated with throttling with the regenerator in the cycle. At the 25,000-pound thrust level, a higher regenerator effectiveness is feasible and can provide a significant increase in achievable chamber pressure, as shown in Figure 27.

The effect of increased thrust chamber heat transfer was determined for both the split-expander cycle (Figure 28) and the full-expander cycle with regeneration (Figure 29). Chamber heat transfer enhancement with a tubular chamber has been estimated to be 18 percent over a milled channel chamber due to the increased hot side surface area. This is the value used in the cycle comparison study. The actual heat transfer enhancement with tubular chambers could be significantly more than 18 percent. An additional 10 percent increase in the predicted heat transfer (110 of 118 percent) could increase chamber pressure by 80 psia for the split-expander cycle and by 60 psia for the full-expander cycle with regeneration. The chamber heat transfer can also be increased by lengthening the thrust chamber.

The baseline length for the candidate cycle thrust chambers is 12.3 inches. Figures 30 and 31 show the impact on chamber pressure of increasing this length to 16 inches for the split-expander cycle and the full-expander cycle with regeneration, respectively. A 14.7 inch chamber length raises the achievable chamber pressure by 95 psia for the split-expander cycle engine. Above that length, however, the coolant pressure loss increase, associated with the enhanced heaf transfer, exceeds its benefits and results in a lower attainable chamber pressure. The full-expander cycle with regeneration experiences an increase in chamber pressure of 54 psia for the same 14.7 inch long chamber.

Based on the above results of this sensitivity study, an extended chamber pressure limit design was generated for each cycle. Moderate levels of improvement were selected for each parameter to stay with optimistic, but not unrealistic, state-of-the-art technology for the mid-1990s. Table 5 lists the chosen improved cycle parameter values. Tables 6 and 7 present the higher chamber pressure cycle data for the split-expander and the full-expander with regeneration, respectively. The split-expander cycle achieves a chamber pressure of 2044 psia with a resulting pump discharge pressure of 6923 psia and an oxygen turbopump turbine inlet temperature of 1556°R. The full-expander cycle with regeneration attains a 2198 psia chamber pressure with a pump discharge pressure of 7572 psia and a turbine inlet temperature of 957°R.

TABLE 5. — CYCLE PARAMETERS IMPROVEMENT VALUES

|                               | Split-Expander<br>Cycle | Full-Expander Cycle W/Regenerator |
|-------------------------------|-------------------------|-----------------------------------|
| Turbine Pressure Ratio        | 2.2                     | 2.2                               |
| Pump Efficiency, %            | +5                      | +5                                |
| Turbine Efficiency, %         | +5                      | +5                                |
| Jacket Bypass, %              | 55                      | N/A                               |
| Regenerator Effectiveness, %  | N/A                     | +10                               |
| Increased Chamber Length, in. | +2.4                    | +2.4                              |

TABLE 6. — ADVANCED ENGINE PARAMETRIC STUDY, SPLIT-EXPANDER ENGINE

| CA                                 | AMBER PRES                 | SIME.            |                          |                  |                  |
|------------------------------------|----------------------------|------------------|--------------------------|------------------|------------------|
|                                    | C ENGINE T                 |                  |                          | 2043.7<br>25000. |                  |
|                                    | TAL ENGINE                 |                  |                          | 52.07            |                  |
|                                    | L. VAC. IS                 |                  |                          | 480.1            |                  |
|                                    | ROAT AREA                  |                  |                          | 5.99             |                  |
|                                    | ZZLE AREA I                |                  |                          | 1000.0           |                  |
|                                    | ZZLE EXIT I<br>GINE HIXTUI |                  |                          | 87.34            |                  |
|                                    | A C4                       | KE KATIU         |                          | 6.00<br>0.993    |                  |
|                                    | AMBER COOL                 | ANT DP           |                          | 1365.            |                  |
|                                    | AMBER COOL                 |                  |                          | 1409.            |                  |
| NO                                 | ZZLE/CHAMBE                | RQ               |                          | 17209.           |                  |
|                                    | FMGTA                      | E STATION        | CONDITIONS               |                  |                  |
| -                                  |                            |                  | 444444444                |                  |                  |
|                                    | • FUEL                     | SYSTEM C         | NOITIONS =               |                  |                  |
| STATION                            | PRESS                      |                  |                          | ENTHALPY         | DENSITY          |
| B.P. INLET                         | 18.6                       | 37.4             |                          | -107.5           | 4.37             |
| B.P. EXIT                          | 100.2                      | 38.4             | 7.44                     | -103.2           | 4.39             |
| PURP INLET                         | 100.2                      | 36.4             | 7.44                     | -103.2           | 4.39             |
| IST STAGE EXIT  JBV INLET          | 2760.6                     | 76.5             | 7.44                     | 65.6             | 4.42             |
| JBV EXIT                           | 2705.4<br>2299.6           | 77.0<br>80.2     | 4.0 <del>9</del><br>4.09 | 65.6             | 4.39             |
| 2ND STAGE EXIT                     | 4890.2                     | 113.3            | 3.35                     | 65.6<br>221.7    | 4.14<br>4.36     |
| PUMP EXIT                          | 6922.8                     | 145.8            | 3.35                     | 369.5            | 4.38             |
| TELLI THAIDOO                      | 6853.6                     | 144.3            | 3.35                     | 369.5            | 4.36             |
| COOLANT EXIT                       | 5489.2                     | 1555.3           |                          | 5507.4           | 0.61             |
| TBV INLET                          | 5433.4                     | 1555.6           |                          | 5507.4           | 0.60             |
| OZ TRB INLET                       | 2408.3<br>5433.4           | 1577.5<br>1555.÷ | 0.17                     | 5507.4           | 0.28             |
| OZ TRB EXIT                        | 4944 7                     | 1517.7           | 3.18<br>3.18             | 5507.4<br>5360.4 | 0.60<br>0.56     |
| HE TRB INLET                       | 4844.3                     | 1517.7           | 3.18                     | 5360.4           | 0.56             |
| M2 TRB EXIT                        | 2571.6                     | 1335.2           | 3.18                     | 4645.6           | 0.34             |
| HZ TRB DIFFUSER                    |                            | 1333.7           | 3.18                     | 4645.6           | 0.34             |
| HZ BST TRB IN<br>HZ BST TRB OUT    | 2482.9                     | 1333.7           | 5.18                     | 4645.6           | 0.34             |
| HC BST TRB DIFF                    | 2462.3<br>2457.1           | 1331.2           | 5.18                     | 4635.6           | 0.53             |
| 02 BST TRB IN                      | 2452.6                     | 1331.4           | 3.18<br>3.18             | 4635.6<br>4635.6 | 0.25             |
| 02 BST TRB OUT                     | 2421.5                     | 1332.0           | 3.18                     | 4630.2           | 0.33             |
| OC BST TRB DIFF                    | 2420.4                     | 1322.0           | 3.18                     | 4630.2           | 0.55             |
| HZ TANK PRESS                      |                            | 1360.9           | 0.0044                   | 4674.0           | 0.0026           |
| GOX HEAT EXCH !N GOX HEAT EXCH !U  |                            | 1342.5           | 3.34                     | 4674.0           | 0.32             |
| MIXER HOT IN                       |                            | 1341.7<br>1341.7 | 3.34<br>3.34             | 4671.0<br>4671.0 | 0.52             |
| MIXER COLD IN                      | 2299.6                     | 80.2             | 4.09                     | 65.6             | 0.32<br>4.14     |
| MIXER OUT                          | 2276.4                     | 622.0            | 7.44                     | 2136.5           | 0.64             |
| FSOV INLET                         | 2276.4                     | 622.0            | 7.44                     | 2136.5           | 0.64             |
| FSOV EXIT                          | 2219.5                     | 622.3            | 7.44                     | 2136.5           | 0.62             |
| CHAMBER INJ<br>CHAMBER             | 2197.3<br>2843.7           | 622.4            | 7.44                     | 2136.5           | 0.62             |
|                                    |                            |                  |                          |                  |                  |
| STATION                            |                            |                  | CONDITIONS               | 4<br>ENTHALPY    | DELECTE          |
| B.P. INLET                         | 16.0                       | 162.7            | 44.7                     | 61.9             | DENSITY<br>70.99 |
| #.P. EXIT                          | 155.2                      | 165.3            | 44.7                     | 62.3             | 70.85            |
| PUMP INLET                         | 135.2                      | 165.3            | 44.7                     | 62.3             | 70.85            |
| PUMP EXIT                          | 3309.8                     | 179.8            | 44.7                     | 72.8             | 71.68            |
| 02 TANK PRESS 0SOV INLET 0SOV EXIT | 16.0                       | 400.0            | 0.074                    | 204.7            | 0.12             |
| OSOV EXIT                          | 2293.7                     | 178.9<br>182.8   | 6.7<br>6.7               | 72.8             | 71.63            |
| OCV INLET                          | 3276.7                     | 178.9            | 37.9                     | 72.8<br>72.8     | 70.12<br>71.63   |
| OCV EXIT                           | 2295.7                     | 182.8            | 37.9                     | 72.8             | 70.12            |
| CHAMBER INJ                        | 2270.7                     | 182.9            | 44.6                     | 72.8             | 70.09            |
| CHAMBER                            | 2043.7                     |                  |                          |                  |                  |
|                                    | •                          | VALVE DAT        | 'A 4                     |                  |                  |
| VALVE                              | DELTA P                    | AREA             | FLOH                     | % BYPASS         |                  |
| JBV                                | 406.                       | 0.15             | 4.09                     | 55.00            |                  |
| TBV                                | 1925.                      | 9.01             | 0.17                     | 5.00             |                  |
| FSOV                               | 57.                        | 1.50             | 7.44                     |                  |                  |
| 0CV                                | *83.                       | 0.21             | 44.63                    |                  |                  |
|                                    | •                          | D ROTCELMI       | ATA .                    |                  |                  |
|                                    | DELTA P                    | 43EA             | FLON                     |                  |                  |
| FUEL                               | 154.                       | 1.15             | 7.44                     |                  |                  |
| COX                                | 227.                       | G.53             | 44.63                    |                  |                  |
|                                    |                            |                  |                          |                  |                  |

# TABLE 6. — ADVANCED ENGINE PARAMETRIC STUDY, SPLIT-EXPANDER ENGINE (Continued)

| *******  | ***********                                 |   |
|--|---|---|
|  | CHINERY PERFORMANCE DATA .                  |   |
|  | *****************                           |   |
|  | **********                                  |   |
| * HC BOOST TURBINE *                             | • H2 BOOST PUMP =                           |   |
| EFFICIENCY (T/T) 0.917                           | EFFICIENCY 0.804                            |   |
| EFFICIENCY (T/S) 0.688                           |   |   |
| SPEED (RPM) 41220.                               | SPEED (RPM) 41228.                          |   |
| MEAN DIA (IN) 2.18                               |   |   |
| EFF AREA (IN2) 1.78                              |   |   |
| U/C (ACTUAL) 0.553<br>MAX TIP SPEED 480.         |   |   |
| STAGES I   |   |   |
| GAPMA 1.43                                       |   |   |
| PRESS RATIO (T/T) 1.01                           | FLOH COEF 0.201                             |   |
| PRESS RATIO (T/S) 1.01                           |   |   |
| HORSEPOHER 45. EXIT MACH MUMBER 0.06             |   |   |
| SPECIFIC SPEED 113.64                            |   |   |
| SPECIFIC DIMETER 0.76                            |   |   |
|  |   |   |
|  | **********                                  |   |
| = H2 TURBINE =                                   | я Н2 РОМР н<br>наменения                    |   |
|  | STAGE OHE STAGE THO STAGE THRE              | F |
|  | **********                                  |   |
| EFFICIENCY (T/T) 0.825                           | EFFICIENCY 0.440 0.575 0.581                |   |
| EFFICIENCY (T/S) 0.787                           |   |   |
| SPEED (RPH) 125000.                              | SPEED (RPM) 125000. 125000. 125000.         |   |
| HORSEPOHER : 3218. HEAN DIA. (IN) 3.30           | SS SPEED 11344.                             |   |
| EFF AREA (IN2) 0.18                              |   |   |
| U/C (ACTUAL) 0.426                               |   |   |
| MAX TIP SPEED 1871.                              |   |   |
| STAGES 2   |   |   |
| GAMMA 1.43                                       | HEAD COEF 0.552 0.530 0.508                 |   |
| PRESS RATIO (T/T) 1.89                           |   |   |
| PRESS RATIO (T/S) 1.96 EXIT MACH MUMBER 0.13     | DIAMETER RATIO 0.306<br>BEARING DN 3.00E+06 |   |
| SPECIFIC SPEED 24.37                             |   |   |
| SPECIFIC DIAMETER 2.39                           | 347 DIACISK 24.00                           |   |
|  |   |   |
| *********  | **********                                  |   |
| ■ 02 BOOST TURBINE ■                             | • 02 BOOST PUMP •                           |   |
| ******************                               | ************                                |   |
| EFFICIENCY (T/T) 0.912<br>EFFICIENCY (T/S) 0.803 | EFFICIENCY 0.803<br>HORSEPOMER 25.          |   |
| SPEED (RPM) 11044.                               | SPEED (RPM) 11044.                          |   |
| MEAN DIA (IN) 5.99                               | S SPEED 3026.                               |   |
| EFF AREA (IN2) 2.45                              | H€AD (FT) 242.                              |   |
| U/C (ACTUAL) 0.553                               | DIA. (IN) 2.73                              |   |
| HAX TIP SPEED 310.                               | TIP SPEED 132.                              |   |
| STAGES 1 GAMMA 1.43                              | VOL. FLOH 283.<br>HEAD COEF 0.450           |   |
| PRESS RATIO (T/T) 1.00                           | FLOH COEF 0.200                             |   |
| PRESS RATIO (T/S) 1.01                           |   |   |
| HORSEPOHER 25.                                   |   |   |
| EXIT MACH MUMBER 0.03                            |   |   |
| SPECIFIC SPEED 54.38                             |   |   |
| SPECIFIC DIAMETER 1.50                           |   |   |
| *********  | 444644444                                   |   |
| . OZ TURBINE .                                   | 4 02 PUMP 4                                 |   |
| *********  | 44444444                                    |   |
| EFFICIENCY (T/T) 0.882                           | EFFICIENCY 0.785                            |   |
| EFFICIENCY (T/S) 0.839                           | HORSEPOHER 662.                             |   |
| SPEED (RPH) 72056.                               | SPEED (RPM) 72054.                          |   |
| HORSEPOHER 662. MEAN DIA (IN) 3.30               | SS SPEED 23942.<br>S SPEED 1690.            |   |
| MEAN DIA (IN) 3.30<br>EFF AREA (IN2) 0.26        | 3 3FEED 1670.<br>H€AD (FT) 6375.            |   |
| U/C (ACTUAL) 0.541                               | DIA. (IN) 2.18                              |   |
| MAX TIP SPEED 1086.                              | TIP SPEED 686.                              |   |
| STAGES 2   | VOL. FLOH 288.                              |   |
| GAMMA 1.43                                       | HEAD COEF 0.436                             |   |
| PRESS RATIO (T/T) 1.12                           | FLOH COEF 0.148                             |   |
| PRESS RATIO (T/S) 1.12                           | DIAMETER RATIO 0.678                        |   |
| EXIT MACH NUMBER 0.06                            |   |   |
| ***************************************          | 95121NG DN 1,445.06                         |   |
| SPECIFIC SPEED 37.64 SPECIFIC DIAMETER 2.05      | SCARING DN 1.44€+06<br>Scaft Diameter 20.00 |   |

# TABLE 7. — ADVANCED ENGINE PARAMETRIC STUDY, FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR

|  |                              |                | CE PARAMET           |                  |                |
|--|------------------------------|----------------|----------------------|------------------|----------------|
|  | ********                     | ********       |                      | ******           |                |
| C  | HAMBER PRES                  | SURE           |                      | 2198.0           |                |
|  | AC ENGINE TO                 |                |                      | 25000.           |                |
|  | OTAL ENGINE<br>EL. VAC. ISI  |                |                      | 52.07<br>480.1   |                |
| 11   | HROAT AREA                   |                |                      | 5.57             |                |
|  | DZZLE AREA I<br>DZZLE EXIT I |                |                      | 1000.0           |                |
|  | STINE MIXTUR                 |                |                      | 84.24<br>6.00    |                |
|  | TA C*                        |                |                      | 0.993            |                |
|  | HAMBER COOL                  |                |                      | 1640.<br>628.    |                |
|  | ZZLE/CHANGE                  |                |                      | 17055.           |                |
|  | EVETA                        | E STATION      | CONDITIONS           |                  |                |
|  |                              |                |                      |                  |                |
|  | 4 5160                       | SVETEN C       | ONDITIONS (          |                  |                |
| STATION  | PRESS                        |                | FLON                 |                  | DENSITY        |
| B.P. INLET   | 18.6                         | 37.4           | 7.45                 | -107.5           | 4.37           |
| B.P. EXIT<br>PUMP INLET                            | 100.9<br>100.9               | 38.4           | _                    | -103.2           | 4.39           |
| IST STAGE EXIT                                     |                              | 38.4<br>72.8   | 7.45<br>7.45         | -103.2<br>51.2   | 4.39           |
| 2ND STAGE EXIT                                     |                              | 105.2          |                      | 202.8            | 4.45           |
| PUMP EXIT  | 7572.0                       | 135.3          |                      | 351.8            | 4.66           |
| COLD REGEN IN                                      | 7496.3<br>7421.4             | 135.9<br>328.4 |                      |                  | 4.63           |
| COOLANT INLET                                      | 7421.4                       | 328.4          | 7.45<br>7.45         | 1107.6           | 2.82<br>2.82   |
| COOLANT EXIT                                       | 5780.9                       | 956.7          | 7.45                 | 5398.4           | 0.99           |
| TBV INLET  | 5723.1                       | 957.1          | 0.37                 | 3398.4           | 0.98           |
| 02 TRB INLET                                       | 2534.9<br>5723.1             | 977.9<br>957.1 | 0.57<br>7.07         | 3398.4<br>3398.4 | 0.46           |
| OZ TRB EXIT  | 5254.2                       | 939.5          | 7.07                 | 3327.0           | 0.98<br>0.92   |
| H2 TRB INLET<br>H2 TRB EXIT                        | 5254.2                       | 939.5          | 7.07                 | \$327.0          | 0.92           |
|  | 2724.4                       | 820.0<br>820.6 | 7.07<br>7.07         | 2848.1           | 0.58           |
| H2 TRB DIFFUSER<br>H2 BST TRB IN<br>H2 BST TRB OUT | 2612.9                       | 820.6          | 7.07                 | 2848.1<br>2848.1 | 0.56<br>0.56   |
|  |                              | 819.6          | 7.07                 | 2843.6           | 0.55           |
| H2 BST TRB DIFF<br>OZ BST TRB IN                   |                              | 819.6          | 7.07                 | 2843.6           | 0.55           |
| 02 BST TRB OUT                                     | 2557.8                       | 819.8<br>819.2 | 7.07<br>7.07         | 2843.6<br>2841.1 | 0.55           |
| 02 BST TRB DIFF                                    | 2549.6                       | 819.2          | 7.07                 | 2841.1           | 0.55<br>0.55   |
| HZ TANK PRESS                                      | 18.6                         | 843.1          | 0.0071               | 2869.0           | 0.0042         |
| GOX HEAT EXCH IN                                   | 1 2536.9<br>IT 2524 2        | 827.1<br>824.8 | 7.44<br>7.44         | 2869.0           | 0.54           |
| GOX HEAT EXCH OU<br>HOT REGEN IN                   | 2524.2                       | 826.8          | 7.44                 | 2867.6<br>2867.6 | 0.54<br>0.54   |
| HOT REGEN EX                                       | 2448.5                       | 614.0          | 7.44                 | 2111.1           | 0.69           |
| FSOV INLET<br>FSOV EXIT                            | 2448.5<br>2387.2             | 614.0          | 7.44                 | 2111.1           | 0.69           |
| CHAMBER INJ  | 2363.4                       | 614.5<br>614.5 | 1.44<br>1.44         | 2111.1<br>2111.1 | 0.67           |
| CHAMBER  | 2198.0                       |                |                      |                  | ****           |
|  | • OXYG                       | EN SYSTEN      | CONDITIONS           | : =              |                |
| STATION  | PRESS                        | TEMP           | FLON                 | ENTHALPY         | DENSITY        |
| B.P. INLET<br>B.P. EXIT                            | 16.0                         | 162.7          | 44.7                 | 61.9             | 70.99          |
| PINE THE ET  | 135.2<br>135.2               | 165.3<br>165.3 | 44.7<br>44.7<br>44.7 | 62.3<br>62.3     | 70.84<br>70.84 |
| PUMP EXIT  | 3559.7                       | 165.3<br>179.9 | 44.7                 | 73.6             | 71.73          |
| 02 TANK PRESS<br>0SOV INLET                        |                              | 400.0          | 0.076                | 204.7            | 0.12           |
| OSOV EXIT  | 3524.l<br>2466.8             | 180.0<br>184.2 | 6.7<br>6.7           | 73.6<br>73.6     | 71.67          |
| OCV INLET  | 3524.1                       | 180.0          | 37.9                 | 73.6             | 70.07<br>71.67 |
| OCV EXIT   | 2466.8                       | 184.2          | 37.9                 | 73.6             | 70.07          |
| CHAMBER INJ<br>CHAMBER                             | 2442.2<br>2198.0             | 184.3          | 44.6                 | 75.6             | 70.05          |
|  |                              |                |                      |                  |                |
|  | •                            | VALVE DAT      | A 4                  |                  |                |
| VALVE  | DELTA P                      | AREA           | FLON                 | 1 SYPASS         |                |
| TBV<br>FSOV  | 3186.                        | 0.01           | 0.57                 | 5.00             |                |
| OCV OCV  | 61.<br>1057.                 | 1.67<br>0.21   | 7.44                 |                  |                |
|  |                              | NUECTOR D      |                      |                  |                |
|  |                              | mutelium ()    | A1A *                |                  |                |
| INJECTOR   | DELTA P                      | AREA           | FLON                 |                  |                |
| FUEL<br>LOX  | 165.<br>244.                 | 1.06<br>0.51   | 7.44                 |                  |                |
| - <del></del> -                                    |                              | 4.51           | ~~.43                |                  |                |

# TABLE 7. — ADVANCED ENGINE PARAMETRIC STUDY, FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR (Continued)

|  | *********   |  |
|--|---|--|
|  | VERY PERFORMANCE DATA +   |  |
| *****************  | ***************************************   | • • • • • •  |
| * 3H18RUT T2008 2H *   | + H2 800ST  |  |
| EFFICIENCY (T/T) 0.876   | EFFICIENCY  | 0.804  |
| EFFICIENCY (T/T) 0.876<br>EFFICIENCY (T/S) 0.476   | EFFICIENCY<br>HORSEPONER  | 46.  |
| SPEED (RPH) 41367.<br>ÆAN DIA (IN) 1,44  | SPEED (RPM)<br>S SPEED  |  |
| EFF AREA (IN2) 5.35  | HEAD (FT)   | \$045.<br>2701.  |
| N/C (ACTUAL) 0.545   | HEAD (FT)<br>DIA. (IN)  | 2.45   |
| MAK TIP SPEED 347.<br>STAGES 1   | TIP SPEED<br>VOL. FLON  | 741  |
| CAPMA 1.41 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01   | HEAD COEF   | 0.450  |
| PRESS RATIO (T/T) 1.01   | FLOH COSF   | 0.201  |
| HORSEPOMER 46.   |   |  |
| EXIT MACH NUMBER 0.08<br>SPECIFIC SPEED 150.00   |   |  |
| SPECIFIC DIAMETER 0.54   |   |  |
|  |   |  |
| * HZ TURBINE *   | * HZ PUR  |  |
| ********   | *******   | •••  |
|  | STAGE ON  | E STAGE THO STAGE THREE  |
| EFF[CIENCY (T/T) 0.866   | EFFICIENCY 8.673  |  |
| EFFICEDICY (T/S) 0.818<br>SPEED (RPH) 125000.  | HORSEPOHER 1625.  | 1598. 1569.<br>125000. 125000.   |
| HORSEPONER 4792.   | SPEED (RPH) 125800.<br>SS SPEED 11284.  | 125000. 125000.  |
| EFF (CLENCY (T/S) 0.818 SPEED (RPH) 125000. HORSEPOWER 4792. REAN DIA. (IN) 2.80 EFF AMEA (IN2) 0.29 U/C (ACTUAL) 0.442 MAX TIP SPEED 1632. STAGES 2   | S SPEED 714.  | 716. 717.  |
| U/C (ACTUAL) 0.442   | HEAD (FT) 80814.<br>DIA. (IN) 3,99  |  |
| MAX TIP SPEED 1632.  | TIP SPEED 2177.   | 2177. 2177.  |
| STAGES 2 GAMMA 1.41  | VOL. FLON 758.  | 735. 717.  |
| PRESS RATIO (T/T) 1.93   | PLOH COEF 8.891   |  |
| PRESS RATIO (T/S) 2.01   | DIAMETER RATIO 8.316<br>BEARING DN 3.80E+86   |  |
| PRESS RATIO (T/S) 2.01 EXIT MACH HUMBER 0.16 SPECIFIC SPEED 38.32 SPECIFIC DIAMETER 1.66   | SHAFT DIAMETER 24.40  |  |
| SPECIFIC DIAMETER 1.64   |   |  |
| *************  | *1600100000   |  |
| - 02 900ST TURBINE +   | # 02 \$00ST (   |  |
| EFFICIENCY (T/T) 0.920   | FFF ICIENCY   | 0.805  |
| EFFICIENCY (T/S) 0.719   | EFF (CLENCY<br>HORSEPOHER<br>SPEED (RPH)<br>S SPEED   | 25.  |
| SPEED (RPM) 11044,   | SPEED (NPM)   | 11044.   |
| EFF AREA (IN2) 4.76  |   |  |
|  | PEAU (F1)   | 242.   |
| MEAN DIA (IN) 6.11<br>EPF AREA (IN2) 6.76<br>U/C (ACTUAL) 0.565  | MEAD (FT)<br>DIA. (IN)  | 2.73   |
| MAK TEP SPEED 235.<br>STAGES 1   | TEP SPEED   | 132.   |
| MAK TIP SPEED 235. STAGES 1 EARMA 1.41   | TEP SPEED   | 132.   |
| MAK TIP SPEED 235. STAGES 1 EARMA 1.41   | TEP SPEED   | 132.   |
| PART TIP SPEED 235. STAGES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 HORSEPOWER 25.   | TEP SPEED   | 132.   |
| PART TIP SPEED 235. STAGES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 HORSEPOWER 25.   | TEP SPEED   | 132.   |
| PART TIP SPEED 235.  STAGES 1  GAMMA 1.41  PRESS RATIO (T/T) 1.00  PRESS RATIO (T/S) 1.00  PRESS RATIO (T/S) 2.5.  | TEP SPEED   | 132.   |
| MAX T(P SPEED 255. STAGES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 HORSEPOWER 25. EXIT HAD MANUER 0.03 SPECIFIC SPEED 103.84 SPECIFIC DIAMETER 0.84  | T (P. SPEED) VOL. FLOW HEAD COOPF FLOW COOPF  | 112.<br>203.<br>0.450<br>0.200   |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 HORSEPOACE 25. EXIT HACH MARRER 0.03 SPECIFIC SPEED 105.84 SPECIFIC DIANETER 0.84   | TEP SPEED   | 112.<br>283.<br>0.450<br>0.200   |
| MAX T(P SPEED 255. STAGES 1 GAMMA 1.41 MESS RATIO (T/T) 1.00 MESS RATIO (T/S) 1.00 MESSPONER 25. EXIT MAD MARBER 0.03 SPECIFIC SPEED 103.86 SPECIFIC DIAMETER 0.84   | TIP SPEED VOL. FLOW HEAD CORP FLOW CORP FLOW CORP   | 112.<br>203.<br>0.450<br>0.200   |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 MESS RATIO (T/T) 1.00 MESS RATIO (T/S) 1.00 MESSPONER 25. EXIT MACH MUMBER 0.03 SPECIFIC SPEED 103.84 SPECIFIC DIAMETER 0.84  ***********************************   | T (P SPEED) VOL. FLOM HEAD CODE FLOM CODE FLOM CODE  ***********************************  | 112.<br>203.<br>0.450<br>0.200   |
| MAX T(P SPEED 255. STACES 1 GAPPIA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS | TIP SPEED VOL. FLOM HEAD CORP FLOM CORP FLOM CORP  ###################################  | 132.<br>203.<br>0.450<br>0.200   |
| MAX T(P SPEED 255. STACES 1 GAPPIA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS | TEP SPEED  VOL. FLON HEAD CORP FLON CORP  FLON CORP  # 02 PUMP ###################################  | 132.<br>203.<br>0.450<br>0.200<br>0.200  |
| MAX TIP SPEED 255. STACES 1 GAPPIA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 0.816 SPECIFIC DIAMETER 0.84  ***********************************  | TEP SPEED  VOL. FLON  HEAD CORP  FLON CORP  | 132.<br>283.<br>0.450<br>0.200<br>0.701<br>0.701<br>715.<br>73901.<br>24501.<br>1440.<br>4872.                         |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS  | TIP SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE  ***********************************  | 132.<br>203.<br>0.450<br>0.200<br>0.701<br>715.<br>73901.<br>24501.<br>1440.<br>4472.<br>2.19                          |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 SPECIFIC SPEED 105.86 SPECIFIC DIAMETER 0.86  ###################################  | TEP SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE  ***********************************  | 132.<br>203.<br>0.450<br>0.200<br>0.200<br>0.78E<br>715.<br>73781.<br>24581.<br>1460.<br>4872.<br>2.19<br>700.         |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS  | TE SPEED VOL. FLOM HEAD CODE FLOM CODE FLOM CODE  # 02 PARP ###################################   | 132.<br>283.<br>0.450<br>0.200<br>0.701<br>715.<br>75981.<br>2450.<br>4872.<br>2.19<br>706.                            |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 SPECIFIC SPEED 103.86 SPECIFIC DIAMETER 0.84  ***********************************   | TIP SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE  ***********************************  | 132.<br>283.<br>0.450<br>0.200<br>0.701<br>715.<br>73901.<br>24501.<br>1640.<br>6072.<br>2.19<br>700.<br>280.<br>0.462 |
| MAX T(P SPEED 255. STAGES 1 GAMMA 1.41 MESS RATIO (T/T) 1.00 MESS RATIO (T/S) 1.00 MESS RATIO (T/T) 0.00 MESS RATIO (T/T) 0.00 MESS RATIO (T/T) 0.00 MESS RATIO (T/T) 0.00 MESS RATIO (T/T) 1.00 MESS  | TEP SPEED VOL. FLON HEAD COEF FLON COEF FLON COEF FLON COEF  FRED CENCY HORSEPONED SPEED (RPM) SS SPEED HEAD (FT) DIA. (IM) TEP SPEED VOL. FLOM HEAD COEF FLOM COEF FLOM COEF GLANTER RATIO BEARING DM  | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |
| MAX T(P SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 SPECIFIC SPEED 103.86 SPECIFIC DIAMETER 0.84  ***********************************   | TIP SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE  ***********************************  | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |
| MAX T(P SPEED 255. STAGES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 SPECIFIC SPEED 105.86 SPECIFIC SPEED 105.86 SPECIFIC DIAMETER 0.86  ###################################   | TEP SPEED VOL. FLON HEAD COEF FLON COEF FLON COEF FLON COEF  FRED CENCY HORSEPONED SPEED (RPM) SS SPEED HEAD (FT) DIA. (IM) TEP SPEED VOL. FLOM HEAD COEF FLOM COEF FLOM COEF GLANTER RATIO BEARING DM  | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |
| MAX TIP SPEED 255. STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS RATIO (T/S) 1.00 SPECIFIC SPEED 105.86 SPECIFIC SPEED 0.86  SPECIFIC DIAMETER 0.86  EFFICIENCY (T/T) 0.896 SPECIFIC (T/S) 0.806 SPECIFIC (T/S) 0.806 SPECIFIC (T/S) 0.806 SPECIFIC (T/S) 0.408 UC (ACTUAL) 0.408 UC (ACTUAL) 0.408 UC (ACTUAL) 0.408 UC (ACTUAL) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 EXIT MACH HUMBER 0.008 SPECIFIC SPEED 45.20 SPECIFIC DIAMETER 1.56  | TE SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE  ***********************************   | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |
| MAX T(P SPEED 255. STAGES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/T) 1.00 PMESS RATIO (T/S) 1.00 PMESS RATIO (T/S) 1.00 PMESS RATIO (T/S) 10.86 SPECIFIC SPEED 105.86 SPECIFIC DIAMETER 0.86  ###################################   | TE SPEED VOL. FLON HEAD CODE FLON CODE FLON CODE FLON CODE  FREED | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |
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| MAX TIP SPEED 255.  STACES 1 GAMMA 1.41 PMESS RATIO (T/T) 1.00 SPECIFIC SPEED 103.86 SPECIFIC DIAMETER 0.84  ***********************************   | TE SPEED VOL. FLOM HEAD CODE FLOM CODE FLOM CODE FLOM CODE FROM CODE FROM CODE SPEED (RMM) SS SPEED S SPEED HEAD (FT) DIA. (IN) TE SPEED VOL. FLOM HEAD CODE FLOM CODE FLOM CODE FLOM CODE FLOM CODE OTAMETER RATIO BEARING DH SHAFT DIAMETER   | 132.<br>283.<br>0.450<br>0.200<br>0.781<br>715.<br>73981.<br>24581.<br>1440.<br>4872.<br>2.19<br>708.<br>280.<br>0.472 |

#### **ENGINE-VEHICLE INTERFACES**

The identified engine-vehicle interfaces are listed in Table 8. Redundant electrical and data connections are suggested for reliability. Each instrumentation cable will carry multiple channels. The number of channels will be determined based on the architecture of the engine-vehicle control interface.

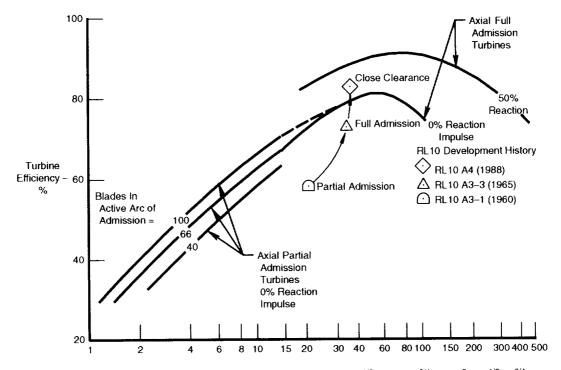
TABLE 8. — ENGINE-VEHICLE INTERFACES

| Description                              | No. of<br>Interfaces |  |
|--|----------------------|--|
| Gimbal Bearing                           | 1                    |  |
| Gimbal Actuator                          | 2                    |  |
| Engine Oxidizer Inlet, Liquid Oxygen     | 1                    |  |
| Engine Fuel Inlet, Liquid Hydrogen       | 1                    |  |
| Fuel Tank Pressurant, Gaseous Hydrogen   | 1                    |  |
| Oxidizer Tank Pressurant, Gaseous Oxygen | 1                    |  |
| Electrical Power                         | 2 <sup>(1)</sup>     |  |
| Pneumatic                                | TBD (0 or 1)         |  |
| Data                                     | 2 <sup>(1)</sup>     |  |
| Notes: (1) Required for redundancy       |                      |  |

The gimbal mount is the primary engine attachment to the vehicle and provides the capability to gimbal the engine through two gimbal actuator attachment points located 90 degrees apart on the engine. The engine is configured with an extendable nozzle to reduce engine storage length. The engine envelope and mechanical interfaces are depicted in Figure 32. The engine lengths (x) and diameter (y) correspond to the dimensions given in Appendix A. The stored length (x') is one-half the total engine length plus 6 to 10 inches depending on engine thrust and undefined vehicle interface requirements.

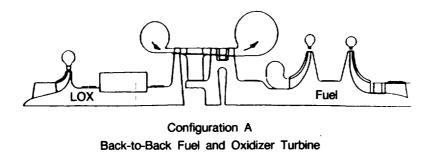
#### REFERENCES

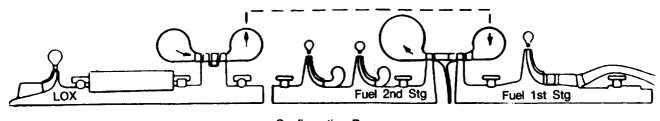
- 1. Smith, T.A.; Pavli, A.J.; and Kacynski, K.J.: "A Comparison of Theoretical and Experimental Thrust Performance of a 1030:1 Area Ratio Rocket Nozzle at a Chamber Pressure of 350 psia." NASA TP-2725, 1987.
- 2. Smith, T.A.: "Boundary Layer Development as a Function of Chamber Pressure in the NASA Lewis 1030:1 Area Ratio Rocket Nozzle." NASA TM-100917, 1988, AIAA-88-3301.



Turbine Stage Specific Speed, N<sub>s</sub> Dimensional = N(Q<sub>EXIT</sub>)<sup>1/2</sup>/(Head<sub>Ad.</sub>)<sup>3/4</sup>; rpm(ft<sup>3</sup>/sec)<sup>1/2</sup>/(ft)<sup>3/4</sup>

Figure 3. Turbine Efficiency Comparison





Configuration B

Back-to-Back Fuel Turbine With Separate Oxidizer Turbine

Figure 4. Back-to-Back Turbine Configurations

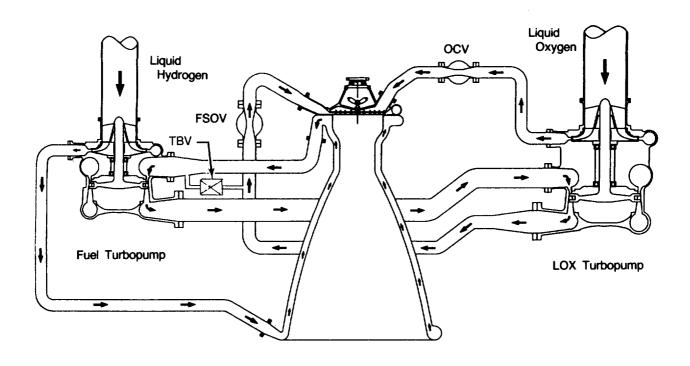


Figure 5. Full-Expander Cycle

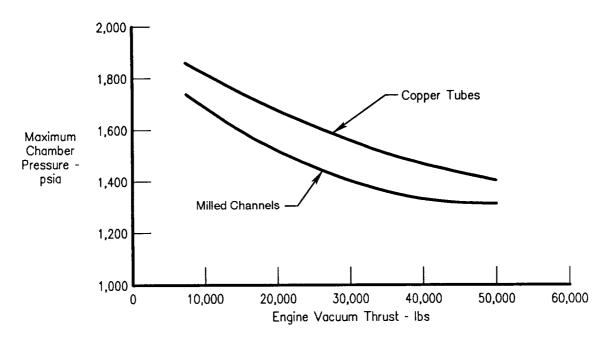


Figure 6. Full-Expander Cycle Achievable Chamber Pressure

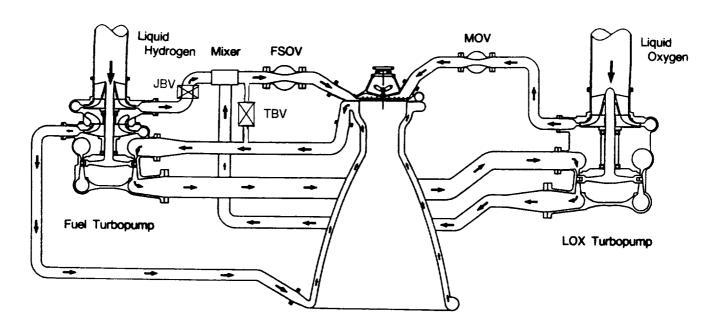


Figure 7. Split-Expander Cycle

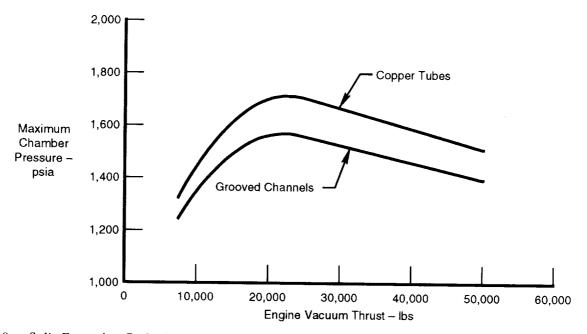


Figure 8. Split-Expander Cycle Achievable Chamber Pressure

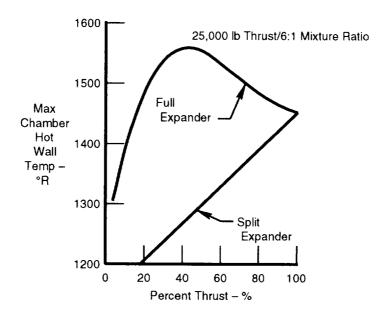


Figure 9. Thrust Chamber Wall Temperatures During Throttling

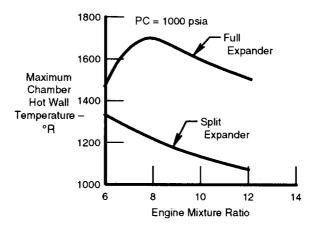


Figure 10. Thrust Chamber Wall Temperature as a Function of High Mixture Ratio

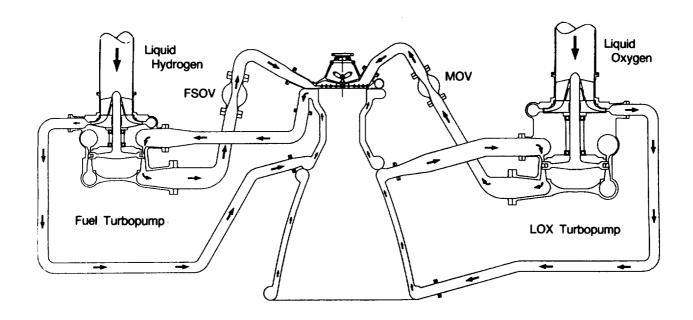


Figure 11. Dual-Expander Cycle

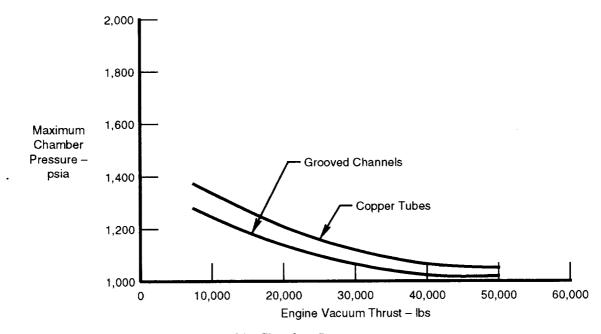


Figure 12. Dual-Expander Cycle Achievable Chamber Pressure

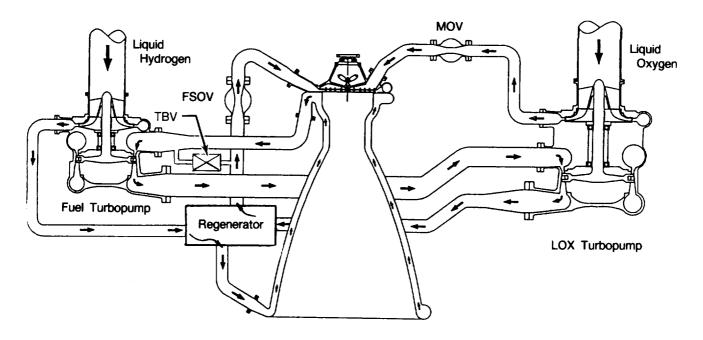


Figure 13. Full-Expander Cycle With Regeneration

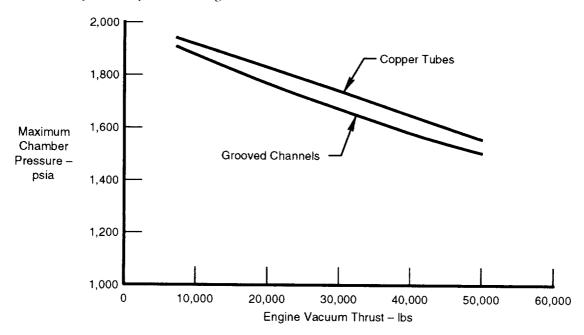


Figure 14. Full-Expander Cycle With Regeneration Achievable Chamber Pressure

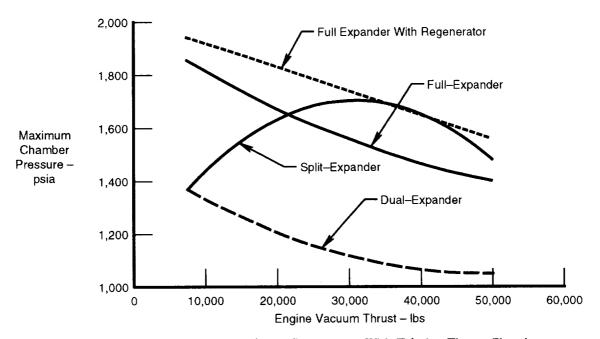


Figure 15. Full, Split, Dual, and Regenerator Cycle Comparison With Tubular Thrust Chambers

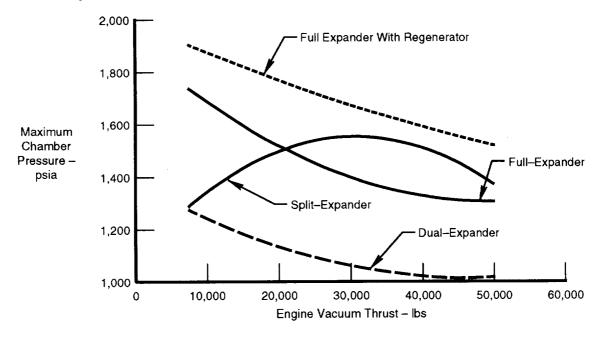


Figure 16. Full, Split, Dual, and Regenerator Cycle Comparison With Milled Channel Thrust Chambers

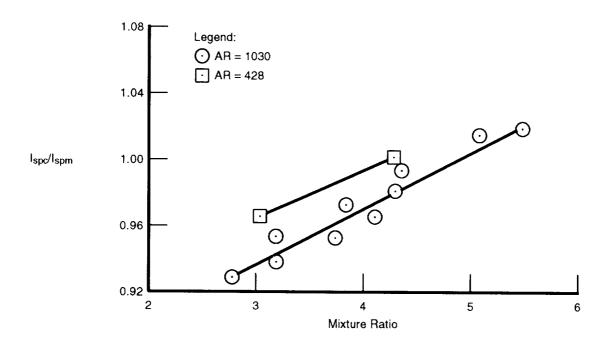


Figure 17. Comparison of Predicted Performance  $(I_{spc})$  With Measured Performance  $(I_{spm})$  for the NASA Lewis High Area Ratio Nozzle (Data From Ref 1)

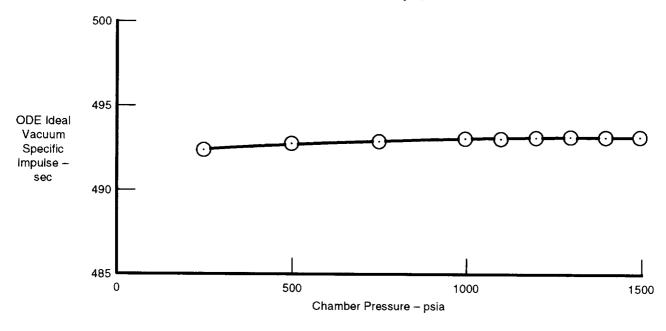


Figure 18. Pratt & Whitney — Rocket Performance Ideal Impulse Versus  $P_c$  for AR = 1000:1, O/F = 6

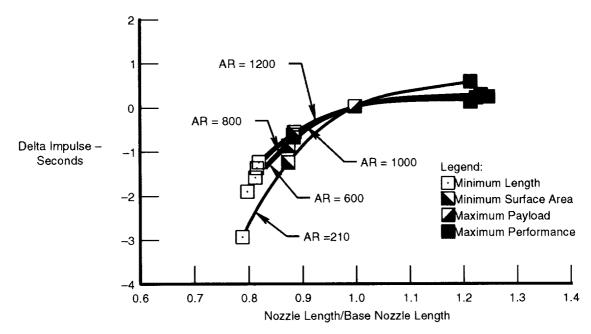


Figure 19. Bell Nozzle Truncation Performance — Length Sensitivity Based on a Maximum Payload Truncation;  $P_c = 1500$ ,  $H_2$ - $O_2$ , O/F = 6.0

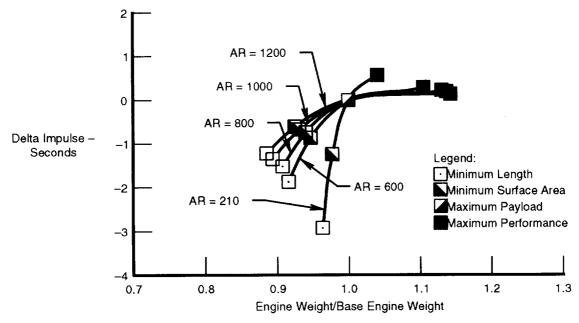


Figure 20. Bell Nozzle Truncation Performance — Weight Sensitivity Based on a Maximum Payload Truncation;  $P_c = 1500$ ,  $H_2$ - $O_2$ , O/F = 6.0

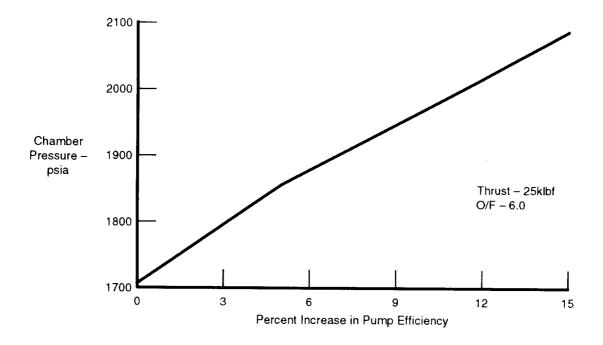


Figure 21. Advanced Split-Expander Cycle P<sub>c</sub> Improvement With Increased Pump Efficiency

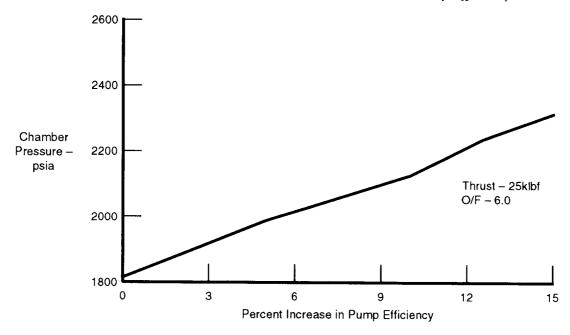


Figure 22. Advanced Full Expander With Regenerator Cycle P<sub>c</sub> Improvement With Increased Pump Efficiency

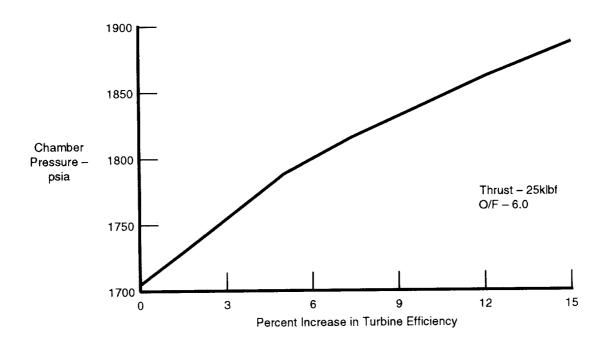


Figure 23. Advanced Split-Expander Cycle P<sub>c</sub> Improvement With Increased Turbine Efficiency

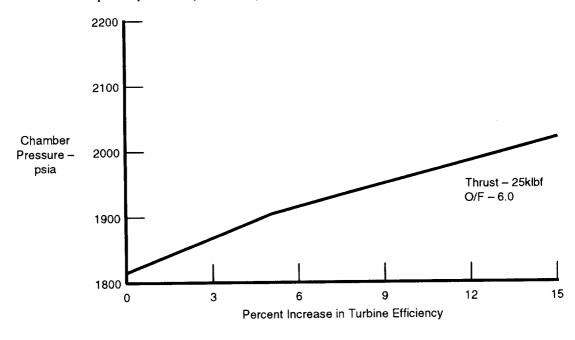


Figure 24. Advanced Full Expander With Regenerator Cycle Pc Improvement With Increased Turbine Efficiency

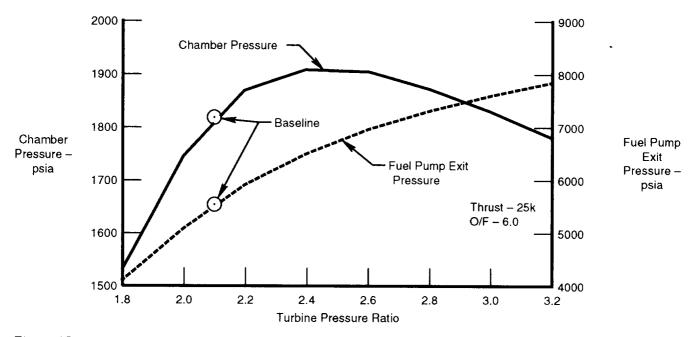


Figure 25a. Advanced Full Expander With Regenerator Cycle P<sub>c</sub> Improvement With Increased Turbine Pressure Ratio

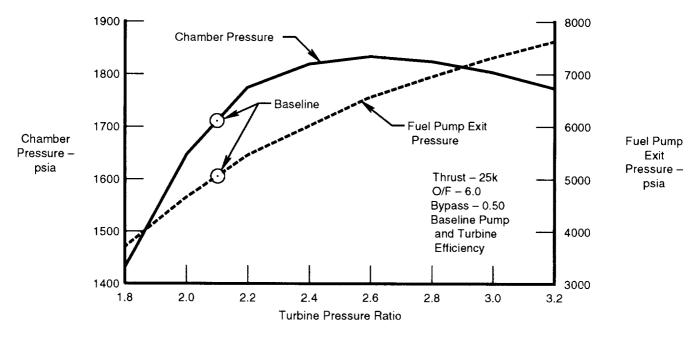


Figure 25b. Advanced Split-Expander With Regenerator Cycle P<sub>c</sub> Improvement With Increased Turbine Pressure Ratio

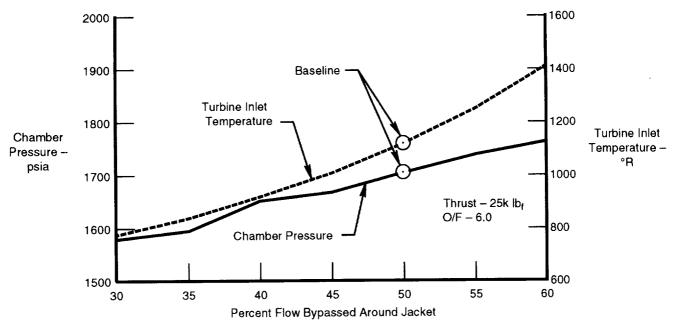


Figure 26. Advanced Split-Expander Cycle Pc Improvement With Increased Bypass Flow Around Jacket

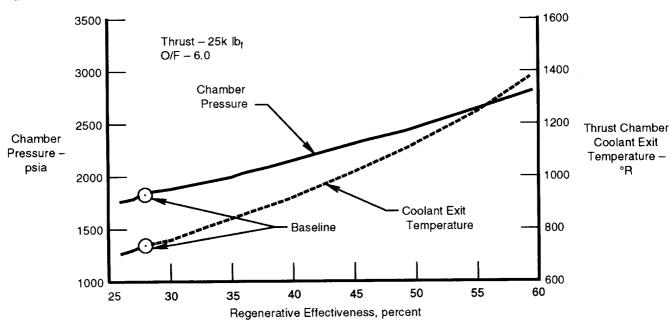


Figure 27. Advanced Full Expander With Regenerator Cycle P<sub>c</sub> Improvement With Increased Regenerator Effectiveness

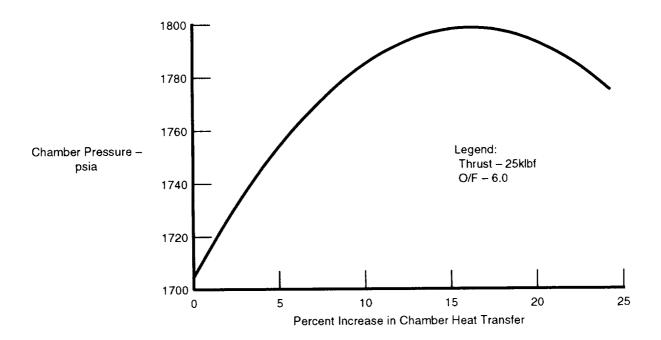


Figure 28. Advanced Split-Expander Cycle P<sub>c</sub> Improvement Due to Increased Chamber Heat Transfer

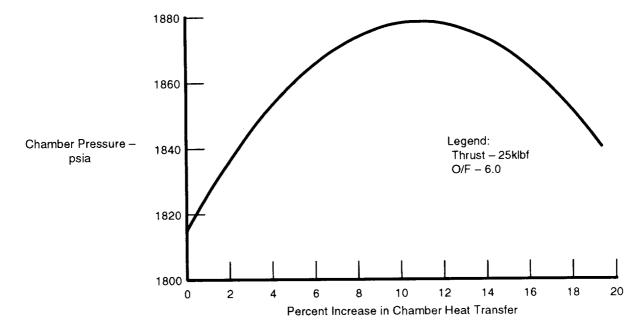


Figure 29. Advanced Full Expander With Regenerator Cycle  $P_c$  Improvement Due to Increased Chamber Heat Transfer

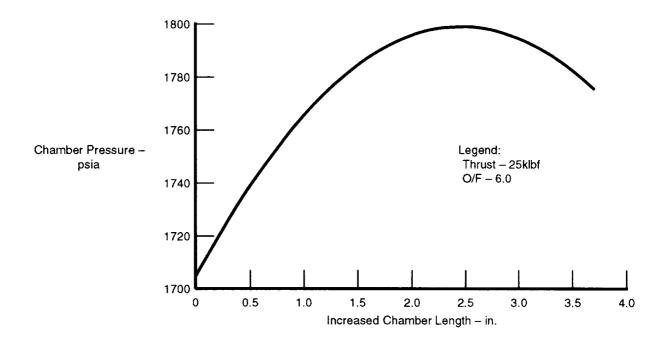


Figure 30. Advanced Split-Expander Cycle P<sub>c</sub> Improvement Due to Increased Chamber Length

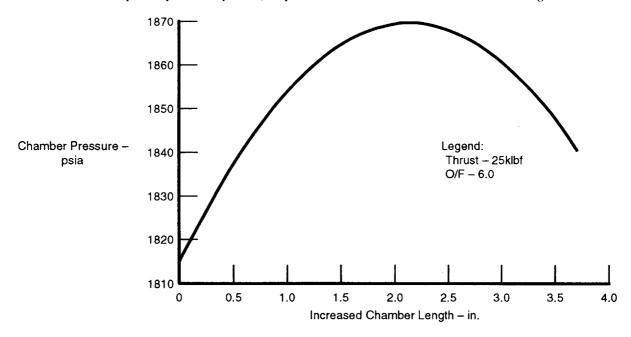
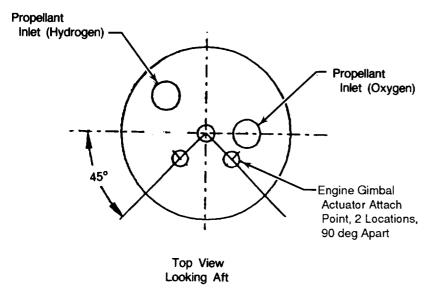


Figure 31. Advanced Full Expander With Regenerator Cycle Pc Improvement Due to Increased Chamber Length



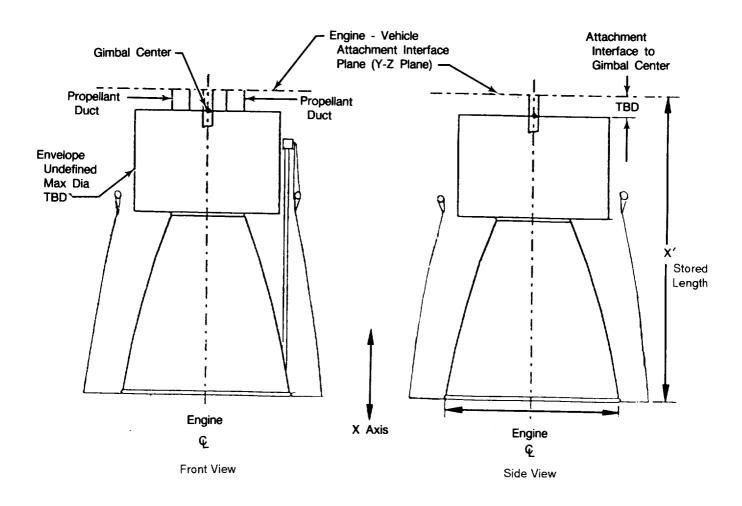


Figure 32. Engine Envelope (Sheet 1 of 2)

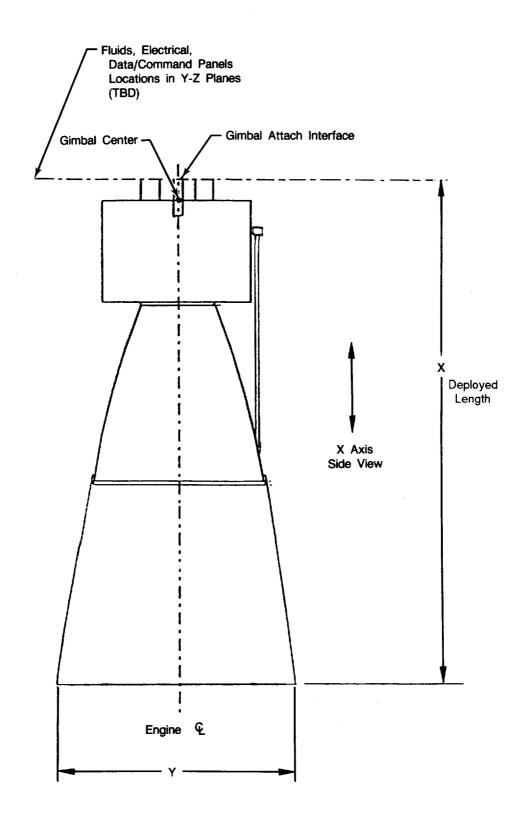


Figure 32. Engine Envelope (Sheet 2 of 2)

# SECTION III THROTTLING AND HIGH MIXTURE RATIO OPERATION

#### COMPONENT REQUIREMENTS

The throttling requirements for the study were set at a minimum throttling capability of 10:1 and an optional requirement of 20:1. The baseline engine mixture ratio requirement was operation from 5.0 to 7.0 ( $6.0 \pm 1.0$ ). An optional requirement was to be able to operate oxidizer rich at a mixture ratio of 12.0. In many respects, the component requirements for wide range throttling and high mixture ratio operation are similar; therefore, the component discussion presented here covers both requirements.

The key technical issues for achieving wide range throttling and high mixture ratio operation are: (1) achievement of high combustion efficiency over a wide thrust and mixture ratio range without excessive system pressure drop and complexity, (2) the ability to adequately cool the thrust chamber over the wide range of conditions required, (3) achievement of wide range control without undue control system complexity, and (4) pump flow stability and avoidance of turbine flow separation at low flowrates. The split expander cycle was selected as the baseline cycle for the throttling and high mixture ratio operation requirements study. The full expander cycle with a regenerator was also considered. The design thrust level was 20,000 lbs.

## **Combustion System**

Low-frequency combustion instability is the primary combustion concern when throttling a rocket engine. Low-frequency instability generally results from a low injector pressure drop being coupled to the combustion process at low thrust. Three methods have been proposed to deal with this problem: high injector pressure drop, dual-orifice injection, and gaseous injection.

The high-pressure drop injector uses a simple, fixed-area injector sized to produce an acceptable pressure loss at the lowest thrust level. However, at full thrust, with the flowrate increased twentyfold for 20:1 throttling, the injector pressure drop becomes very high, resulting in high pump discharge pressure requirements. The extra power required to meet the high discharge pressure requirements significantly reduces the achievable cycle combustion chamber pressure.

The dual-orifice injection concept provides wide range throttling capability without requiring high oxidizer injector pressure drops at full thrust or oxidizer vaporization for gaseous injection. Separate control of the primary and secondary oxidizer flow provides an adequate pressure drop through the primary at all flow conditions. At low thrust all flow is diverted through the primary orifices, and, at intermediate thrust, the primary is used to energize and atomize the secondary flow. The dual-orifice concept was derived from gas turbine engine fuel injection technology and has successfully demonstrated high performance over a wide range of conditions. Under Contracts AF-04(611)-9565, -9575, and -11611, the injector shown in Figure 33 demonstrated throttling ratios of 170:1 with fluorine/hydrogen. A similar concept using a dual-manifold tangential entry slot oxidizer element was tested in the XLR-129 oxygen/hydrogen preburner (Contract F()4(611)-68-C-0002) at pressures over 5000 psia (Figure 34). The XLR-129 tangential entry dual-orifice injection concept is currently being used in the preburner for the SSME Alternate Turbopump Development (ATD) preburner injectors. Extensive spray characterization has been completed under the ATD program. Figure 35 shows a single ATD preburner injection element at 100 percent of design flow.

Gaseous oxidizer injection also offers an effective method of achieving low-frequency combustion stability at low-thrust levels. The dual expander cycle is aimed specifically at providing gaseous oxidizer for injection. Mixing the gaseous oxidizer with the gaseous fuel over a wide range of operating conditions, however, is more difficult than gas-liquid mixing, and lower combustion efficiency is likely to be encountered at some operating conditions.

A heat exchanger may be used with a fixed-area injector to provide gaseous oxygen at an acceptable pressure drop at low thrust while maintaining reasonable injector pressure losses with liquid oxidizer at full thrust. This concept has been proposed as a solution to low-frequency instability in earlier advanced space engines (the RL10 IIB and the OTV engine), but these engines did not have the requirement for continuous throttling. An engine using a heat exchanger in conjunction with a single-element injector would require a more complex control system to provide continuous throttling over the desired 20:1 range.

Based on this comparison, a dual-orifice injector was selected for additional evaluation for the study on the basis of its versatility and potentially high combustion efficiency at full thrust, throttled, and high mixture ratio conditions.

# **Thrust Chamber Cooling**

Rocket engine cooling with throttling can present difficult design challenges. If the entire fuel flow is used for cooling, as thrust level decreases, the coolant exit temperature increases. The temperature increases because with a fixed-geometry thrust chamber, a reduction in thrust is accompanied by a proportional decrease in chamber pressure and coolant flow, while the heat flux is reduced by approximately chamber pressure to the 0.8 power. Under some conditions, the increasing coolant temperature can cause the thrust chamber wall temperature to increase as the engine is throttled. If the wall temperature at full thrust is near the upper limit (as is desirable to minimize coolant pressure drop), the allowable upper limit at reduced thrust may be exceeded. The upper curve in Figure 36 shows a typical example. Cooling limits can be partially offset by reducing combustion length, use of higher thrust chamber contraction ratio, use of overcooling at the design point, or bypassing part of the flow at the design point and using all of the flow at off-design condition. Each of these approaches reduces the cooling problem at throttled conditions, but each imparts a cycle loss, increased thrust chamber weight and volume, added control system complexity, or some combination of these design penalties.

The split expander provides a means of avoiding the throttling constraint associated with most other cycles. Because of the reduced coolant flow at full thrust, the coolant exit temperature of the split expander is higher than with a full-expander cycle. By controlling the split-expander jacket bypass flow to increase the percent of coolant flow, the coolant exit temperature can be decreased up to a point during throttling. At some fraction of rated power (30 percent in the case studied), the jacket bypass valve is completely closed, and the cycle operates like a full-expander cycle. However, because the coolant passages for the split expander are designed for low flowrate, the combustor wall stabilizes at a lower temperature during deep throttling, as shown in the lower curve on Figure 36.

High mixture ratio operation is also enhanced with the split-expander cycle. By controlling the coolant jacket bypass flow to increase the percent of coolant flow, operation at higher mixture ratio levels with lower combustor wall temperatures is possible. Figure 37 shows the cooler wall temperatures attained with the split expander cycle compared to a typical cycle.

Low wall temperatures are essential at high mixture ratio operation. The maximum temperature for prevention of copper oxidation is 1060 to 1260°R without coatings. Use of coatings could reduce this limitation, but proven coatings are not currently available, and any coating will reduce the overall heat flux and the available cycle power.

The full-expander cycle with regeneration also offers the potential for control of thrust chamber wall temperatures. By reducing the amount of regeneration, the thrust chamber coolant temperature is reduced. The cooling benefit of reducing the amount of regeneration is partially offset by the higher coolant density and lower cooling velocity. Thus, cooling at throttled conditions with a regenerator in the cycle is more difficult than throttled cooling with a split-expander cycle. Also, care must be taken not to reduce the amount of regeneration at low thrust to the point that unacceptably low coolant velocity results. Figure 38 compares the coolant exit

temperature for the case of all of the fuel passing through the regenerator with a case where a portion of the jacket exit flow bypasses the regenerator. (The control scheme for bypassing the regenerator is presented below.) Without partial bypassing of the regenerator, the coolant jacket exit temperature greatly exceeds the allowable copper wall temperature. With partial bypassing, the jacket wall temperature is held within acceptable limits, as shown in Figure 39.

# Wide Range Control

A conceptual control system for the split-expander cycle is shown in Figure 40. The jacket bypass valve (JBV) is used to control the coolant jacket flow for throttled and high mixture ratio operation. The JBV also contributes to thrust control. The oxidizer secondary control valve controls the oxidizer flow split between the primary and secondary injector flow and provides mixture ratio control by throttling the oxidizer flow. These two valves can also provide control of thrust down to approximately 60 percent. For deep throttling, a turbine bypass valve is used to control thrust by reducing turbine power.

In the split-expander cycle, liquid hydrogen enters the engine inlet and flows through a single-stage boost pump and proceeds onto a three-stage main pump. After the first stage of the main pump, 50 percent of the hydrogen flow is diverted and routed through the JBV and to the mixer. The remainder of the hydrogen flow is sent through the second and third stages of the pump to attain the high pressure required by the cycle and is then used to cool the chamber and nozzle. A small fraction of the gaseous hydrogen leaving the nozzle coolant exit is diverted through the turbine bypass valve (TBV) and flows into the mixer. The rest of the coolant hydrogen flow first powers the main hydrogen and oxygen turbines before being routed to the hydrogen and oxygen boost turbines. The turbine flow is then used to provide energy to the oxidizer tank pressurant through a heat exchanger and enters the mixer to join the bypass flows. The combined hydrogen flow then exits the mixer, flows through the fuel shutoff valve (FSOV), and enters the injector for combustion in the main chamber. On the oxidizer side, liquid oxygen enters the engine and flows through a single-stage boost pump and a single-stage main pump. After exiting the main pump, the oxygen is split between the primary and secondary legs of the injector, with the secondary flow controlled by the oxidizer flow control valve (SOCV). The flow routed through the primary side flows through the primary oxidizer shutoff valve (POSV). The oxygen flow is subsequently injected into the main chamber to combust with the hydrogen.

Figure 41 shows a conceptual control system for the full-expander cycle with regeneration. Because the full-expander cycle has no bypass flow, thrust control is achieved entirely by the turbine bypass valve. The turbine bypass flow is routed around the regenerator heat exchanger. As thrust is reduced, the amount of bypass flow increases, thereby reducing the amount of regeneration.

In the full-expander cycle with regeneration, liquid hydrogen enters the engine inlet and flows through a single-stage boost pump and proceeds onto a three-stage main pump. After exiting the main pump, the hydrogen flows pass through a regenerator before being used to cool the chamber and nozzle. A small portion of the gaseous hydrogen leaving the nozzle coolant exit is diverted around the turbines through the turbine bypass valve (TBV). The majority of the hydrogen flow is used to power the main hydrogen and oxygen turbines before being routed to the hydrogen and oxygen boost turbines. After leaving the oxygen boost turbine, the flow travels through the regenerator and mixes with the flow which bypassed the turbines. The hydrogen then continues on through the fuel shutoff valve (FSOV) and enters the injector for combustion in the main chamber. The oxidizer side of the cycle has the same configuration as the split-expander cycle. The liquid oxygen enters the engine and flows through a single-stage boost pump and a single-stage main pump. After exiting the main pump, the oxygen flow is split between the primary and secondary legs of the injector, with the secondary flow being controlled by the oxidizer flow control valve (OCV). The flow routed through the primary side passes through the primary oxidizer shutoff valve (POSV) and is subsequently injected into the main chamber to combust with the hydrogen.

# **Turbomachinery**

The turbomachinery concerns when throttling a rocket engine are flow stability on the pump side and flow separation on the turbine end. As the rocket engine is throttled, propellant flowrates and turbopump speeds both decrease. The main pump tends to come down an operating line like that shown in Figure 42. As the pump enters the low-capacity region, the head coefficient drops off, and the pump flow becomes unstable. One method of avoiding this is to recirculate a percentage of the flow from the pump exit to the inlet; in effect maintaining a higher volumetric flow at the low-thrust levels. However, this increases the total enthalpy entering the pump and may cause the pump to cavitate. To overcome this, the boost pump can be operated in a manner to produce a higher pressure to the main pump, which together with the recirculated flow can effectively eliminate both instability and cavitation. In addition to pump recirculation, several design features may be used to enhance pump stability with throttled operation. One method is use of an inducer-interstage strut. The inlet struts serve to minimize induced pre-swirl during throttled conditions, thereby providing a steepened headflow characteristic for improved pump stability. Figure 43 shows how these characteristics increased the head coefficient in the 350K and XLR-129 high pressure fuel turbopumps, thereby allowing significant increases in throttleability.

Vaneless pump discharge collectors should be used on all stages, as opposed to stall-prone collectors with incidence-sensitive vane or pipe diffusers. All stages should also employ low discharge blade angles to steepen the head-flow characteristics for improved stability. Various advanced seal configurations may be used to minimize parasitic leakages detrimental to pump stability at low flowrates. Moderate suction specific speed requirements have been selected at design and off-design operation to avoid cavitation-induced instabilities. Various throttle aids such as inlet back-flow collectors can also be employed.

Turbine flow separation is primarily a performance concern rather than an operational concern. The throttling analysis completed under this study showed that the 20:1 range resulted in turbines which are close to separation. One advantage that was demonstrated by the split-expander cycle is that, since the turbine is designed for only half the flow at full thrust, when the engine is throttled down to 5 percent thrust, the turbine has more flow separation margin in it than the full-expander cycle.

#### CYCLE DATA

The split-expander cycle and full-expander cycle with regeneration were selected for more detailed engine studies. These studies consisted of an engine throttling investigation and a mixture ratio variation study. The thrust chamber and nozzle configuration chosen for both the split expander and the full expander with regeneration is shown in detail in Figure 44. The thrust chamber is 12.3 inches long, has a contraction ratio of 4.0, and is constructed from copper tubing. The regenerative nozzle extends out to an area ratio of 210 to 1, and is built from Haynes 230 tubing. A composite material nozzle extension increases the overall area ratio to 1000 to 1. The design point selected for the throttling studies for each cycle is defined as follows:

|                         | Split Expander | Full Expander With Regeneration |
|-------------------------|----------------|---------------------------------|
| Vacuum Thrust Level, lb | 20 <b>K</b>    | 20 <b>K</b>                     |
| Inlet Mixture Ratio     | 6.0            | 6.0                             |
| Chamber Pressure, psia  | 1612           | 1764                            |

Detailed cycle sheets for the full-thrust design thrust levels are located in Appendix B for each of the engine cycles examined.

## Split-Expander Cycle

A throttling investigation was performed on the split-expander cycle, with cycle points generated at 100, 50, 10, and 5 percent of the design thrust level while holding the mixture ratio constant at 6.0. (The throttled cycle sheets detailing this investigation are located in Appendix C.) During engine throttling in the split-expander cycle, the JBV, which was previously shown in Figure 40, is used to increase the percent of hydrogen flow available to cool the thrust chamber/nozzle assembly. This increased coolant flow lowers the coolant exit temperature with thrust level, as shown in Figure 45, while the JBV area decreases according to the schedule shown in Figure 46. At 10 percent thrust the JBV is completely closed, and the cycle reverts to a full expander with all of the hydrogen flow being used to cool the thrust chamber. As a result, the coolant exit temperature below 10 percent thrust increases. The TBV opens (Figure 47) as thrust level decreases, allowing a greater percentage of the coolant flow to bypass the turbine and causing system pressures and pump speeds to drop.

A major concern during deep throttling is low frequency combustion instability resulting from low oxidizer injector pressure drops ( $< 5\% \Delta P/P_c$ ). Dual-orifice injection allows the effective injection area to be varied with thrust level, giving an acceptable average injector pressure loss both at low thrust and full thrust, as shown in Figure 48. The oxygen is injected using tangential swirl elements to promote momentum exchange between the primary and secondary streams and the net injection velocity is sufficient for good atomization and efficiency.

A mixture ratio sensitivity study was done on the split expander cycle for mixture ratios of 5 to 7 and 12 at the 20 klb thrust design level. The cycles generated for this study are given in Appendix D. A plot of chamber pressure and chamber/nozzle heat transfer versus mixture ratio is shown in Figure 49 for the 5 to 7 range.

Below the O/F of 6.0 level chamber pressure is lower than the design point chamber pressure, which can be attributed to the reduced heat flux caused by the lower combustion temperature and increased power requirements to accommodate the higher fuel flows. The reduced heat flux limits the available cycle power by decreasing the turbine inlet temperature. The TBV is closed to maintain chamber pressure. When the 5 percent margin designed into the cycle reaches 0 as the O/F is lowered, chamber pressure and, subsequently, thrust decline. Conversely, above an O/F of 6.0, there is a surplus of energy available to the turbine, and chamber pressure and thrust can be maintained by opening the TBV. On the other side of stochiometric, at a mixture ratio of 12.0, the heat flux in the chamber is again below the design level so that the maximum chamber pressure is limited to 1250 psia. The inlet fuel flow is nearly 50 percent of design, so the JBV is closed, making all of the fuel available for use as a coolant and turbine flow. With the increased mixture ratio, the horsepower split between the fuel and oxidizer turbopumps changes and the fuel side is overpowered by the flow required by the oxidizer turbine. To compensate for this, the fuel shutoff valve (FSV) is throttled to create a higher line loss downstream of the turbines and to load the fuel system. The FSV must close to approximately 36 percent of its design flow area.

### Full-Expander Cycle With Regenerator

A throttling study was also conducted for the full-expander cycle with regeneration. The throttled cycles generated were at 50, 10, and 5 percent of the 20,000 lbs design thrust at a mixture ratio of 6.0. Detailed cycle sheets for these throttled points are contained in Appendix C.

Unlike the split-expander cycle, the coolant flow cannot be controlled during throttling and, with the chamber designed for full coolant flow, the coolant exit temperature rises during engine throttling, as shown in Figure 50. At the 5 percent thrust level, the turbine inlet temperature is above 1200°R. The TBV opens during throttling (Figure 51), bypassing a greater percentage of the hydrogen flow around the turbine, dropping pump speeds and system pressures. Since the energy for the hot side of the regenerator is supplied by the turbine discharge flow, as thrust decreases, the lower flowrate results in a relatively small increase in coolant inlet temperature (Figure 52).

As with the split-expander cycle, a major concern during deep throttling is low-frequency combustion instability resulting from low oxidizer injector pressure drops ( $< 5\% \Delta P/P_c$ ). To maintain the required pressure loss without having to vaporize the oxygen, the dual-orifice injector concept was used in the full-expander cycle studies. The dual-orifice injector allows the effective injection area to be varied with thrust level, giving an acceptable average injector pressure loss both at low thrust and full thrust, as shown in Figure 53. The oxygen is injected utilizing tangential swirl elements to promote momentum exchange between the primary and secondary streams, and the net injection velocity is sufficient for good atomization and efficiency.

Using the 20 klb thrust level as the design point, a mixture ratio sensitivity study was conducted with the full-expander cycle with regeneration. The specific O/Fs studied were from 5 to 7 and 12.0. Detailed cycle sheets for these operating points are contained in Appendix D. A plot of chamber pressure and chamber/nozzle heat transfer versus mixture ratio is shown in Figure 54. The characteristics display the same trends for the full-expander cycle with regeneration as those seen with the split expander cycle. At the lower O/F levels, the cycle runs out of power and chamber pressure falls off. The coolant and turbine flow for the full-expander cycle with regeneration, operating at high mixture ratio, is much lower than the design value; consequently, turbopump performance suffers and the achievable chamber pressure is lower. At the mixture ratio of 12.0, the chamber pressure drops to 1160 psia. As with the split-expander cycle, the FSV must be throttled to load the fuel system. The valve is closed to under 10 percent of its design value. The selected control system with partial regenerator bypass, as was previously shown in Figure 41, provides lower coolant exit temperature than achievable without turbine bypass, but temperatures are still above current acceptable limits for copper thrust chambers. Either improved materials, or a more complex control system that provides complete regenerator bypass, would be required to achieve operation at a mixture ratio of 12.0. Either approach would be expected to reduce achievable chamber pressure over some portion of the mixture ratio range.

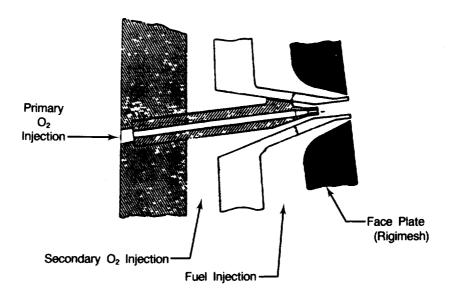


Figure 33. Coaxial Dual Area Orifice Injector

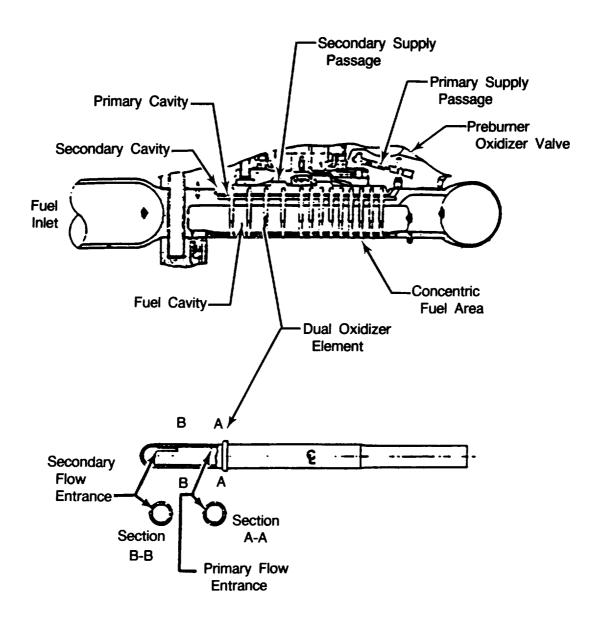


Figure 34. XLR-129 Demonstrator Engine Preburner Injector With Dual Tangential Entry Injection

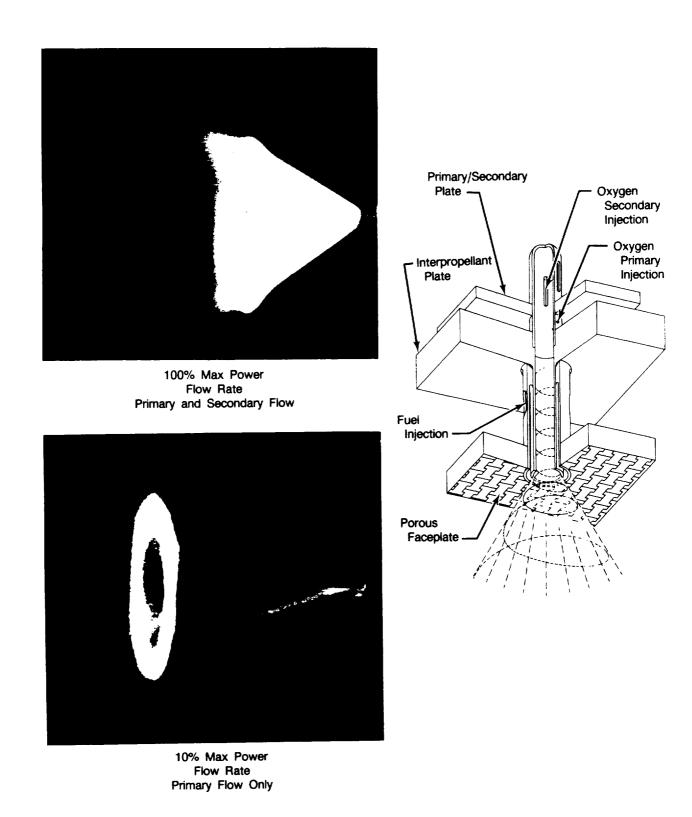


Figure 35. Tangential Entry Dual-Orifice Injection

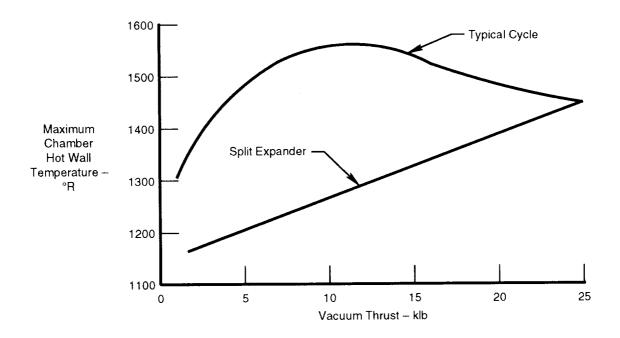


Figure 36. Maximum Thrust Chamber Wall Temperature With Throttling for a Typical Cycle and for the Split-Expander Cycle

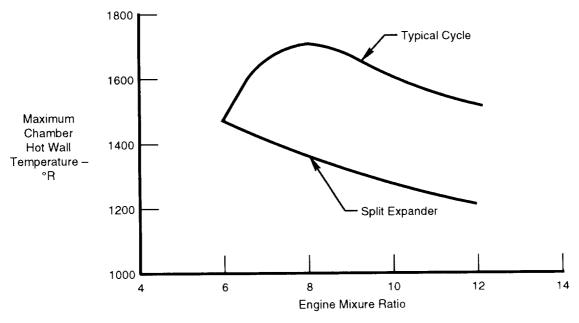


Figure 37. Comparison of Thrust Chamber Wall Temperature Versus Mixture Ratio for Typical and Split-Expander Cycles

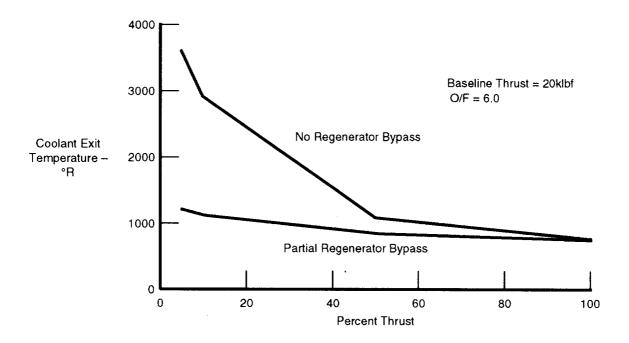


Figure 38. Coolant Exit Temperature Versus Percent Thrust for the Full-Expander Cycle With Regeneration

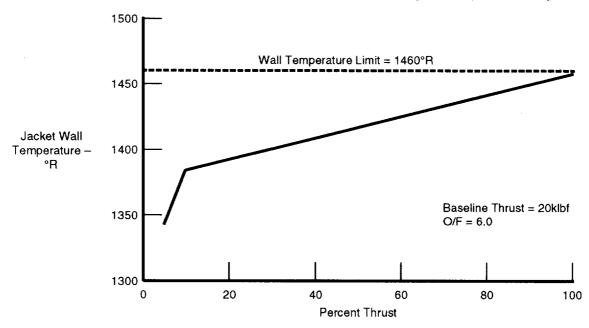


Figure 39. Jacket Wall Temperature Versus Percent Thrust for the Full-Expander Cycle With Regeneration

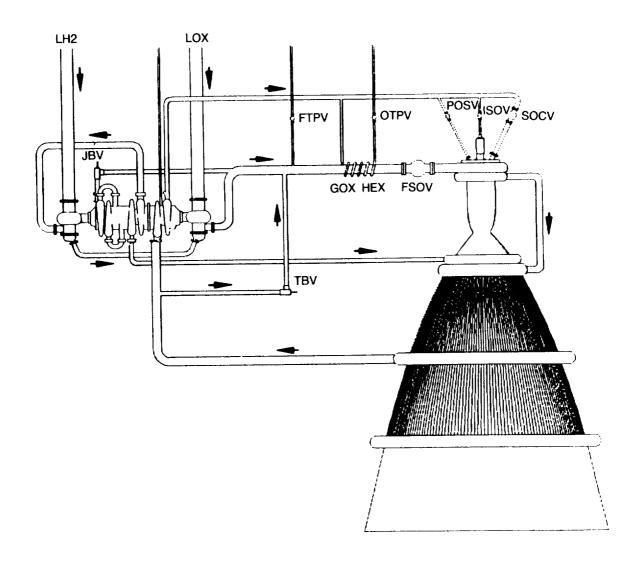


Figure 40. Space Engine Control Schematic — Split-Expander Cycle

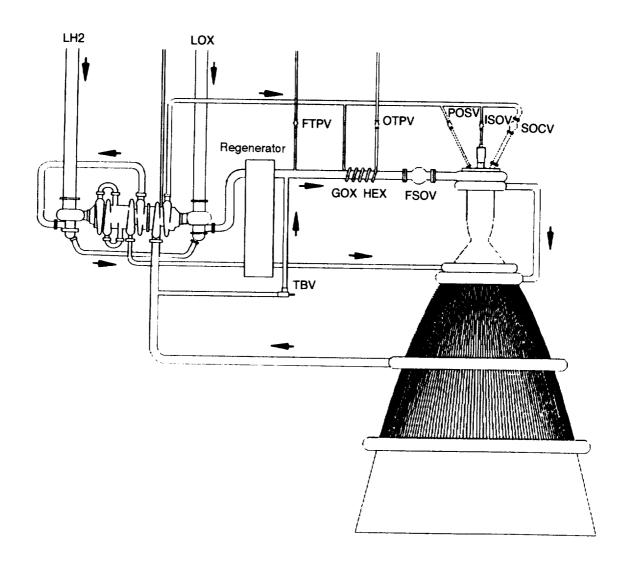


Figure 41. Space Engine Control Schematic — Full-Expander Cycle With Regeneration

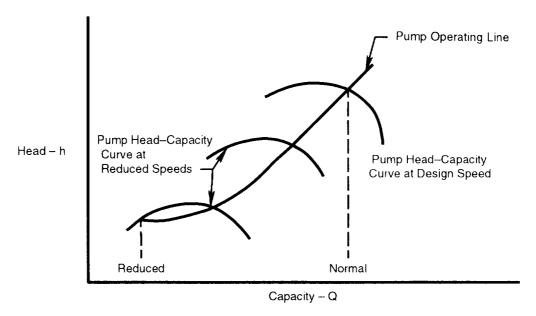


Figure 42. Typical Turbopump Head-Capacity Curve

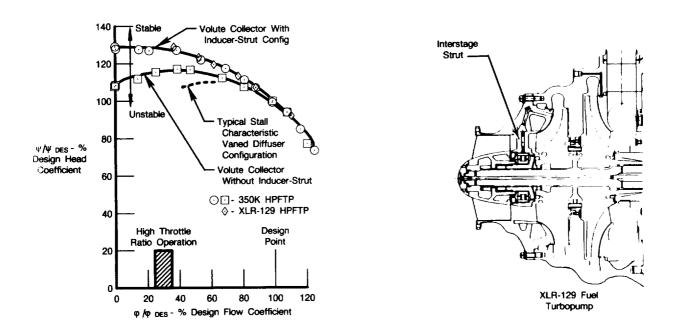


Figure 43. Volute Collector With Inducer Struts Provides Head-Flow Characteristics

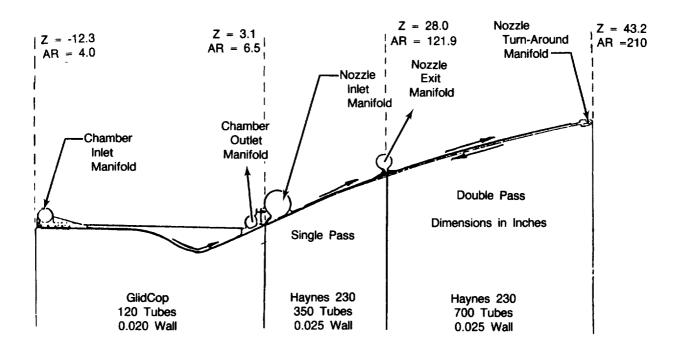


Figure 44. Thrust Chamber and Nozzle Cooling Configuration for the Full-Expansion Cycle With Regeneration and the Split-Expander Cycle

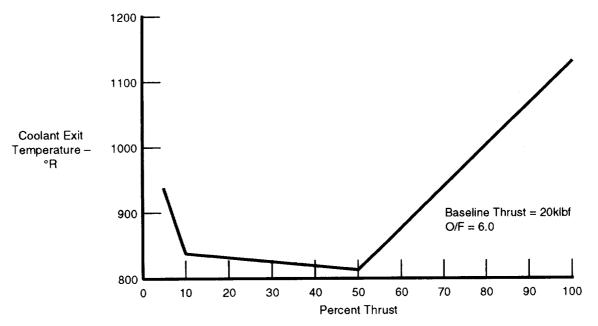


Figure 45. Split-Expander Cycle Throttling, Coolant Exit Temperature Versus Percent Thrust

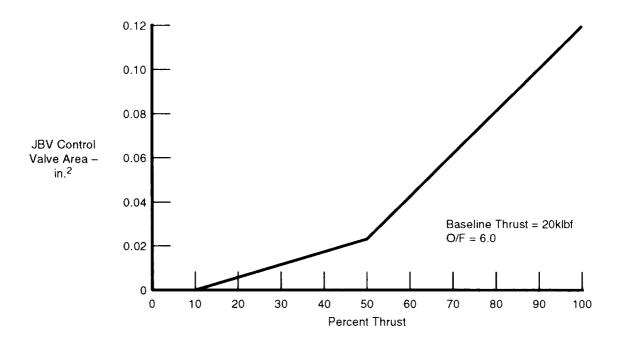


Figure 46. Split-Expander Cycle Throttling, JBV Control Valve Area Versus Percent Thrust

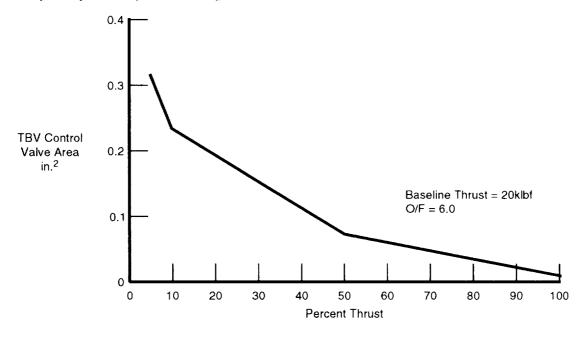


Figure 47. Split-Expander Cycle Throttling, TBV Control Valve Area Versus Percent Thrust

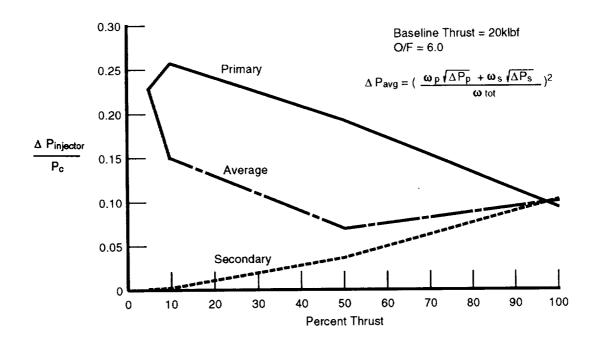


Figure 48. Split-Expander Cycle Throttling, Ratio of  $\Delta P$  Across Injector to  $P_c$  Versus Percent Thrust

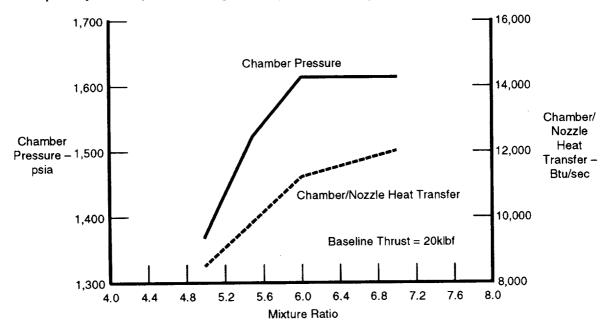


Figure 49. Split-Expander Cycle Chamber Pressure, and Nozzle Heat Transfer Versus Mixture Ratio

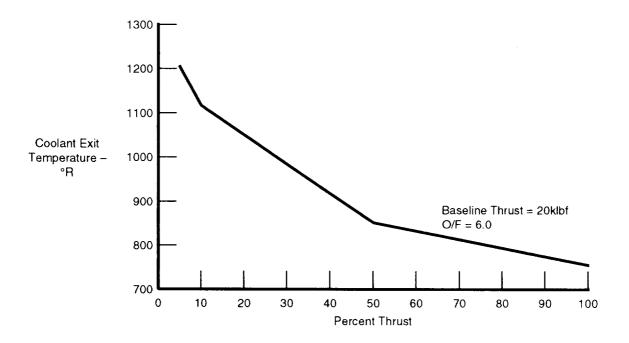


Figure 50. Full Expander With Regenerator, Coolant Exit Temperature Versus Percent Thrust

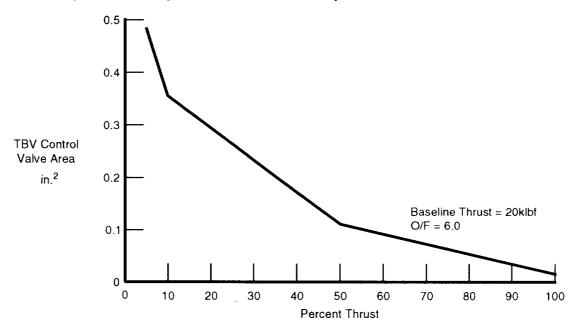


Figure 51. Full Expander With Regenerator, TBV Control Valve Area Versus Percent Thrust

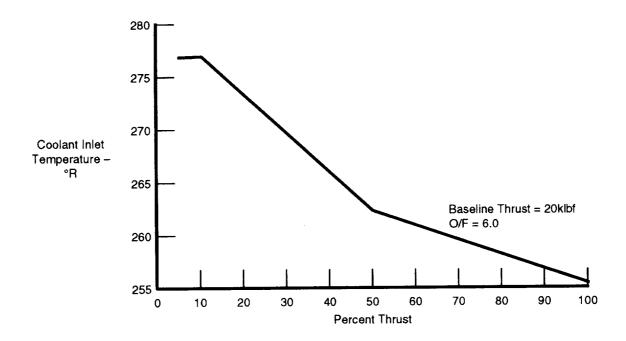


Figure 52. Full Expander With Regenerator, Coolant Inlet Temperature Versus Percent Thrust

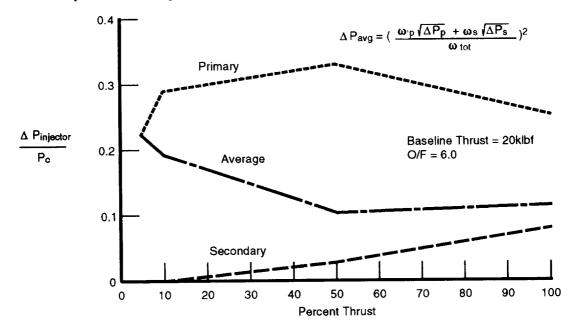


Figure 53. Full Expander With Regenerator, Ratio of  $\Delta P$  Across Injector to  $P_c$  Versus Percent Thrust

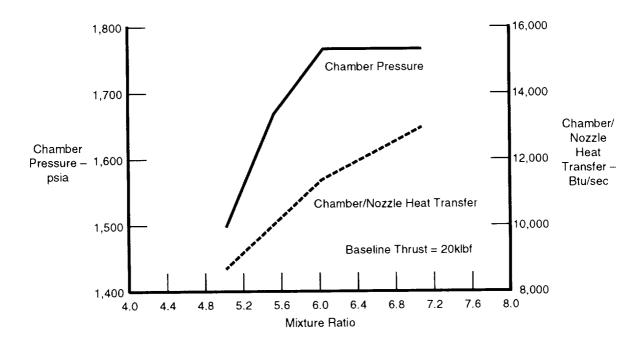


Figure 54. Full-Expander Cycle With Regenerator, Chamber Pressure and Chamber/Nozzle Heat Transfer Versus Mixture Ratio

# SECTION IV RECOMMENDATIONS

Based upon the results of this study and related ongoing space engine studies at Pratt & Whitney, the following recommendations are offered:

- Steps should be taken to investigate the key technology issues associated with design and fabrication of copper tubular thrust chambers. These issues include: (a) determination of the heat transfer enhancement associated with tubular chambers compared to smooth wall chambers, (b) determination of cyclic structural life increases associated with copper tubes over milled channel construction, and (c) investigation of copper tube chamber fabrication techniques to take full advantage of the total heat transfer and life advantages of copper tubular chambers.
- 2. The study should be expanded to investigate optimum cycles and design approaches for expander cycle engines in the 50 to 200klbf thrust range.
- 3. Interface definition should be expanded in conjunction with system requirement definitions from vehicle contractors.
- 4. Performance and envelope data should be updated as performance and technology levels become better defined from such sources as the NASA-LeRC high area ratio performance investigations and focused technology programs.

# APPENDIX A PARAMETRIC DATA

Parametric data are presented in Figures 55 through 107.

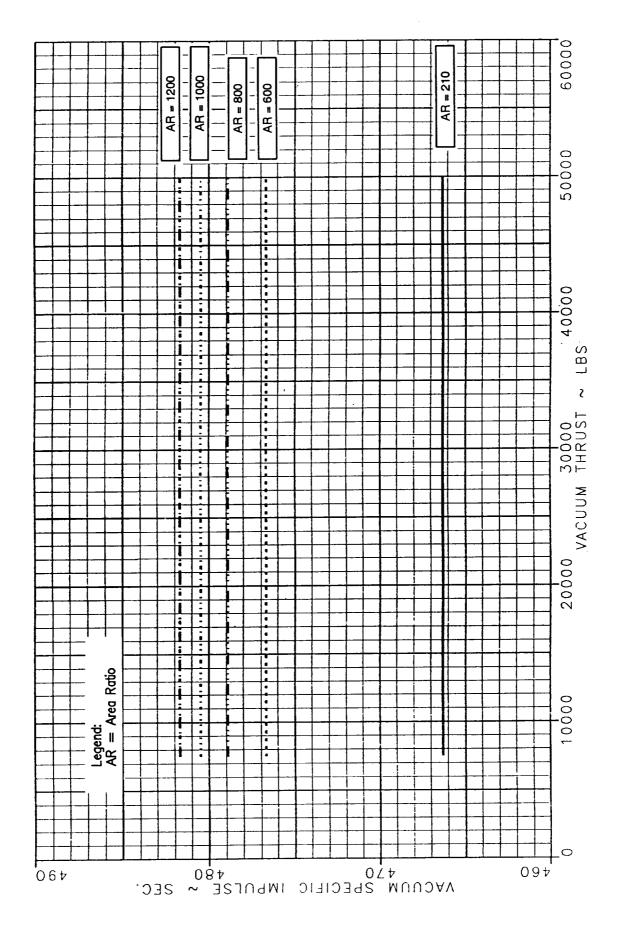


Figure 55. Ivac Versus Vacuum Thrust for Chamber Pressure = 1000 psia

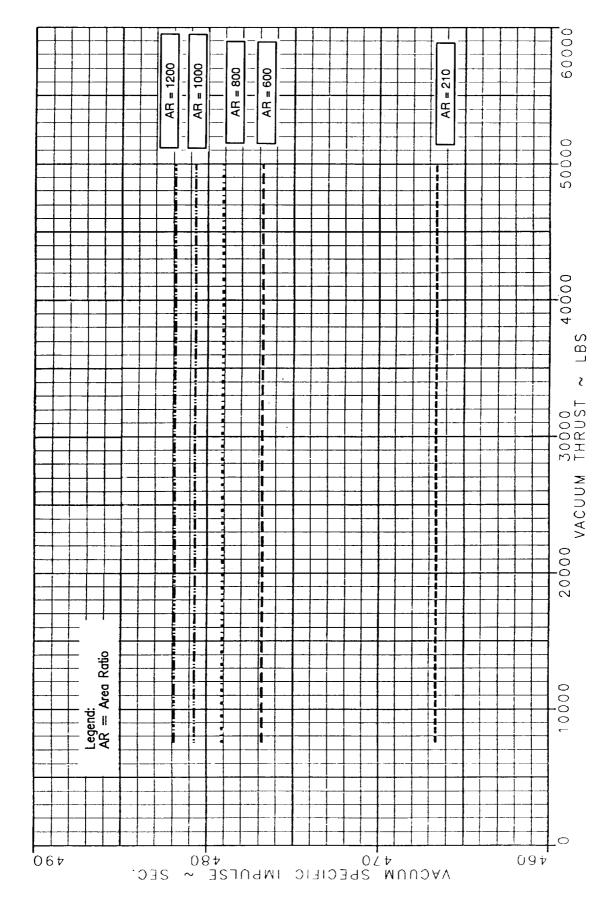


Figure 56. Ivac Versus Vacuum Thrust for Chamber Pressure = 1500 psia

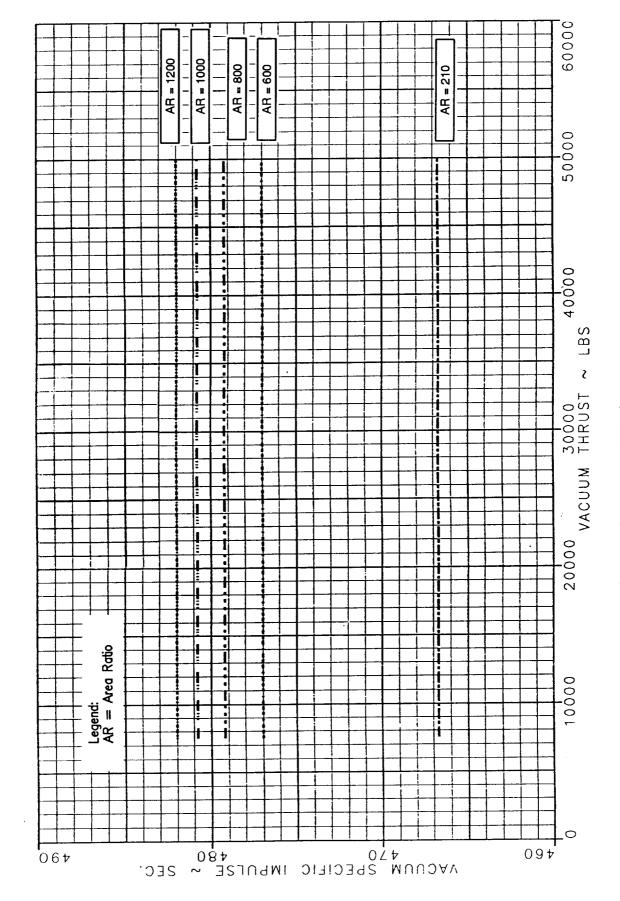
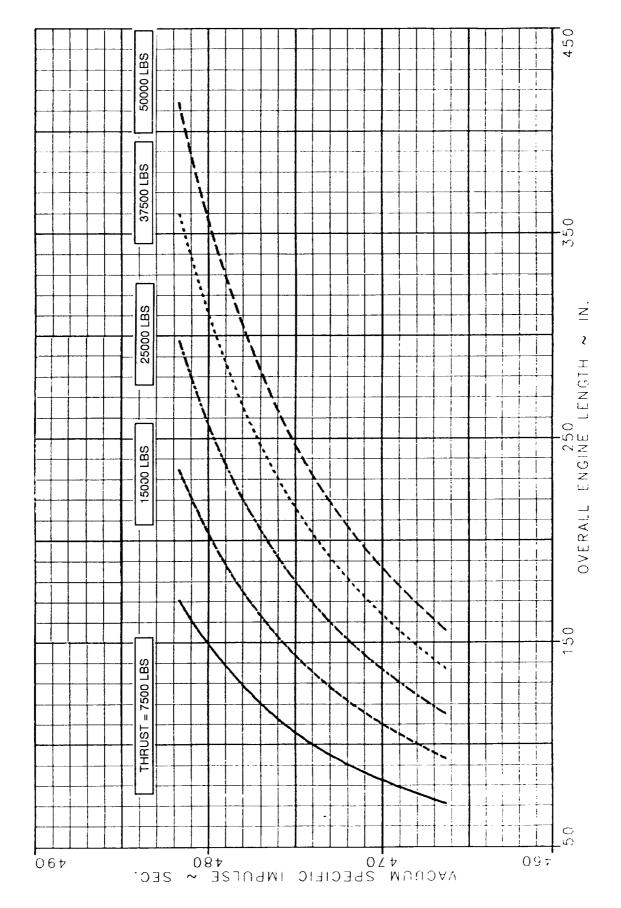
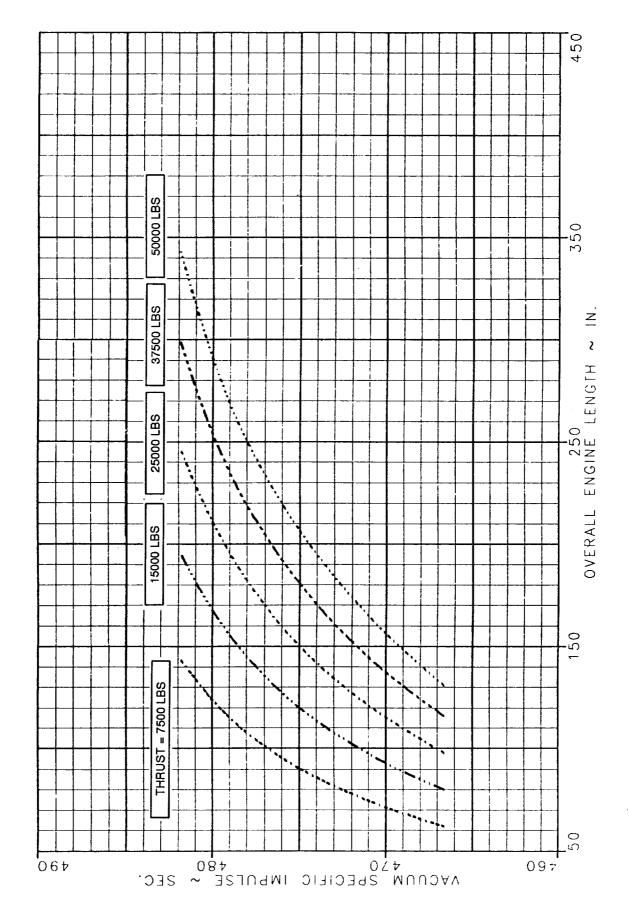


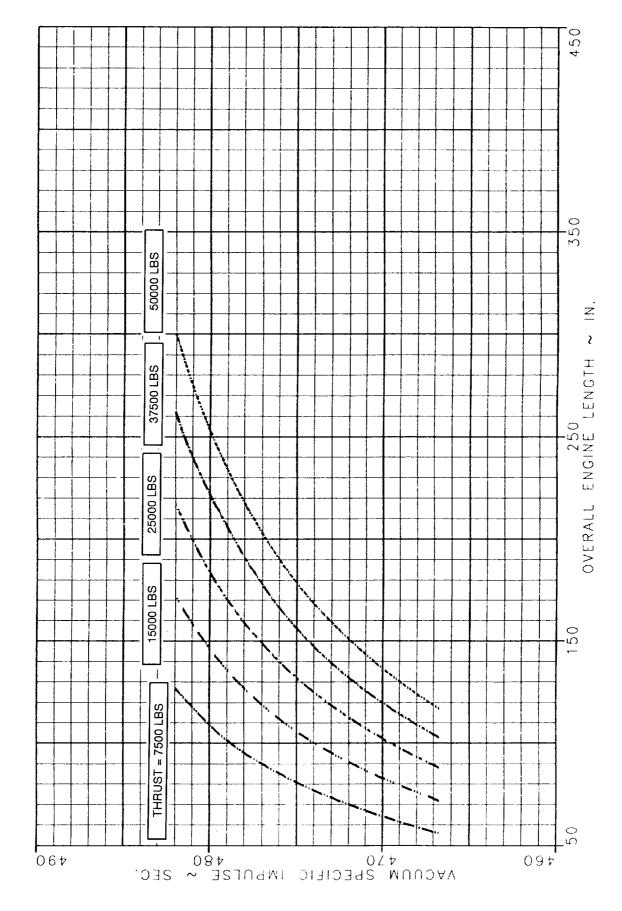
Figure 57. Ivac Versus Vacuum Thrust for Chamber Pressure = 2000 psia



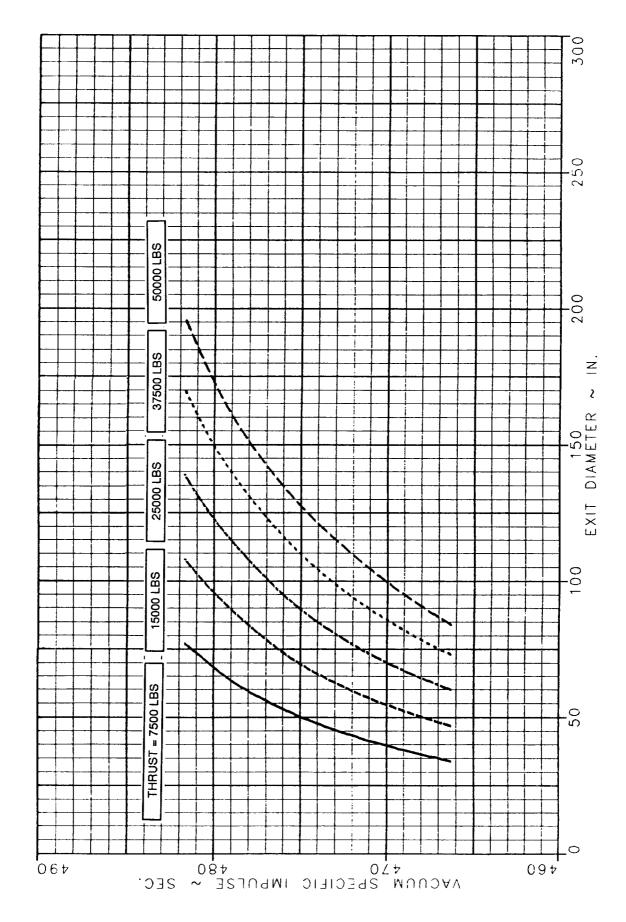
Vacuum Specific Impulse Versus Length for Chamber Pressure = 1000 psia Figure 58.



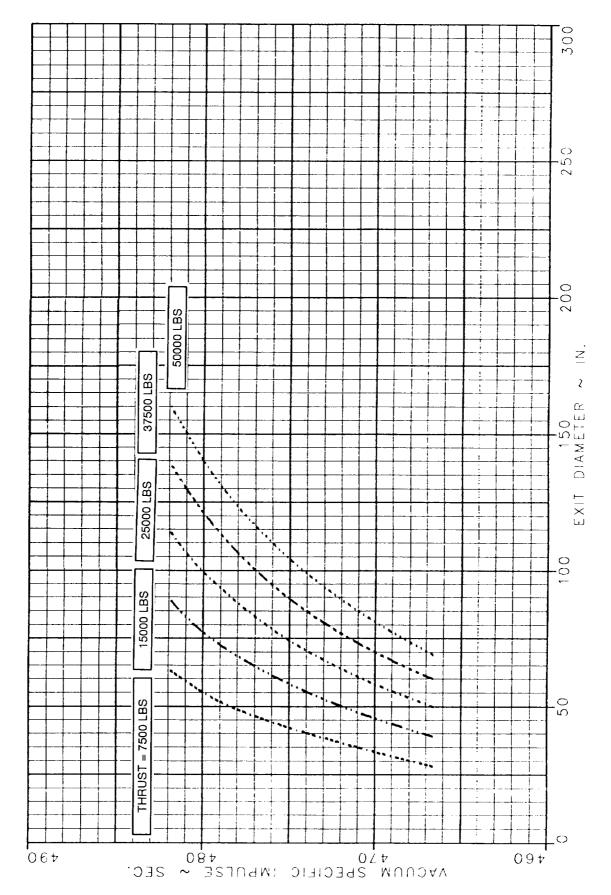
Vacuum Specific Impulse Versus Length for Chamber Pressure = 1500 psia Figure 59.



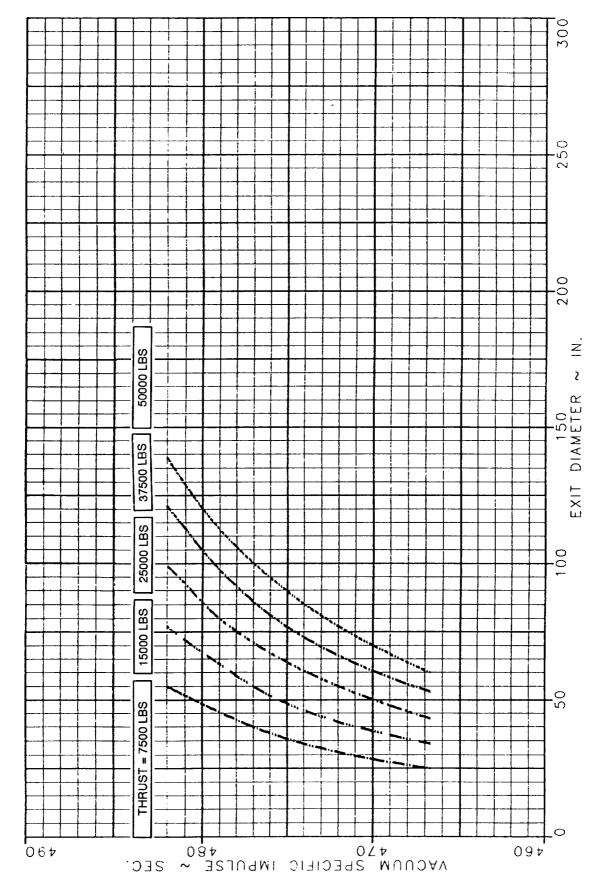
Vacuum Specific Impulse Versus Length for Chamber Pressure = 2000 psia Figure 60.



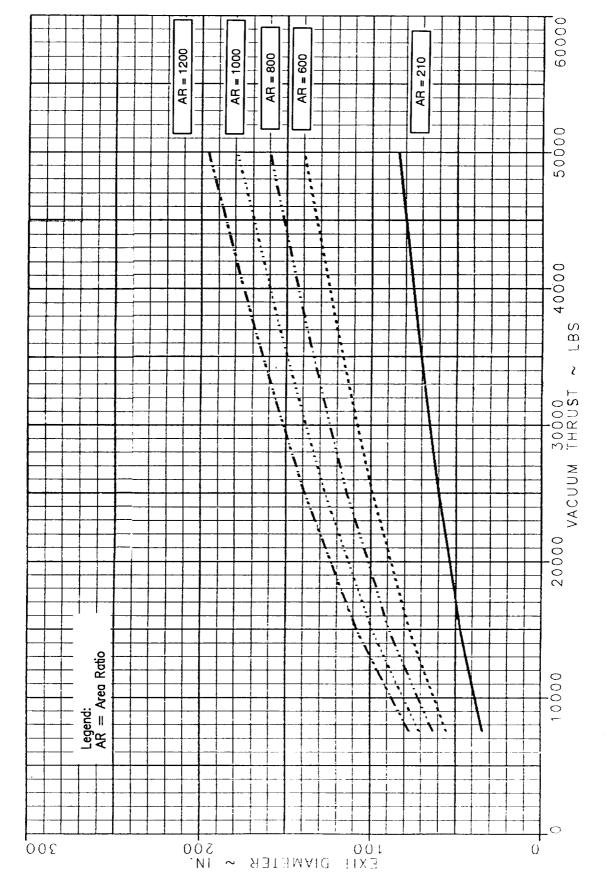
Vacuum Specific Impulse Versus Diameter for Chamber Pressure = 1000 psia Figure 61.



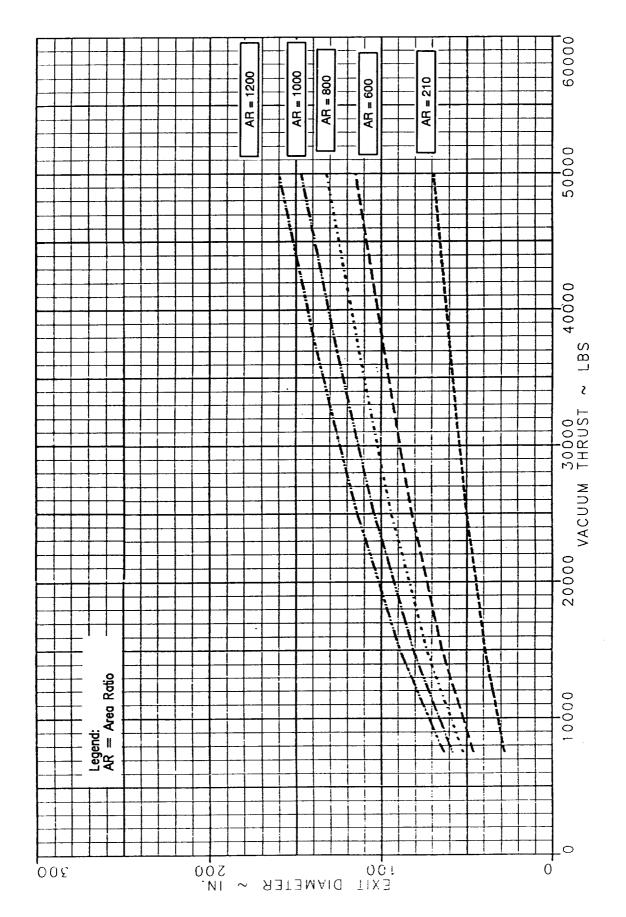
Vacuum Specific Impulse Versus Exhaust Nozzle Exit Diameter for Chamber Pressure = 1500 psia Figure 62.



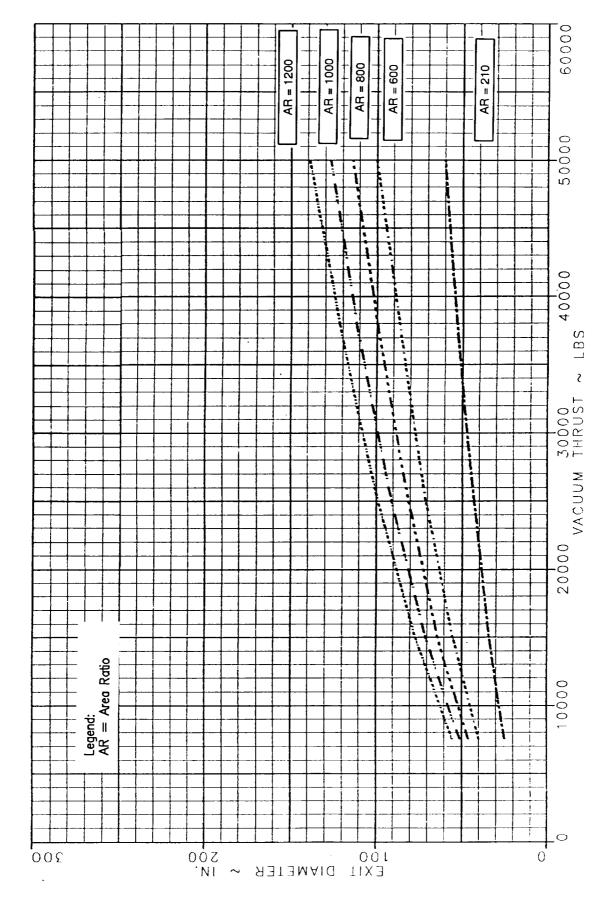
Vacuum Specific Impulse Versus Exhaust Nozzle Exit Diameter for Chamber Pressure = 2000 psia Figure 63.



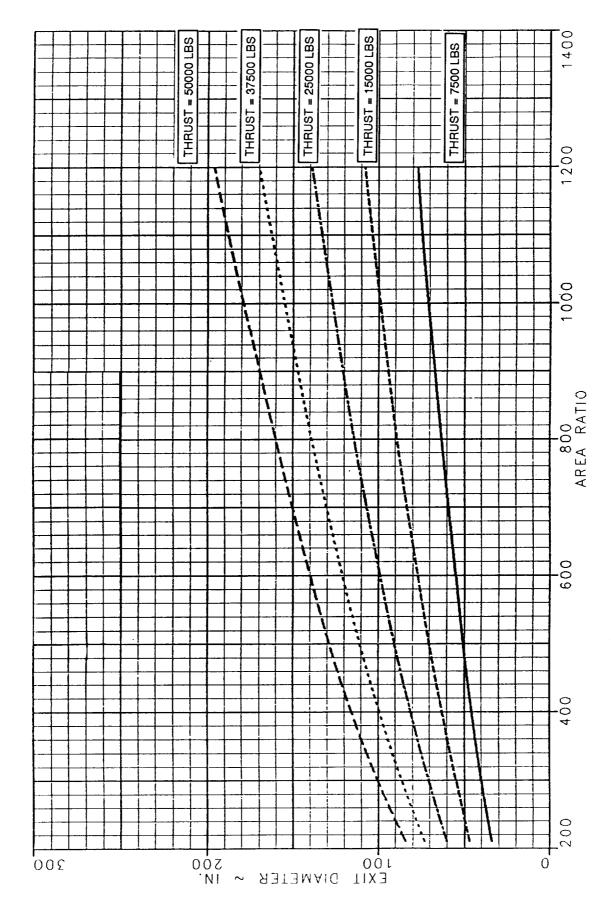
Exhaust Nozzle Exit Diameter Versus Thrust for Chamber Pressure = 1000 psia Figure 64.



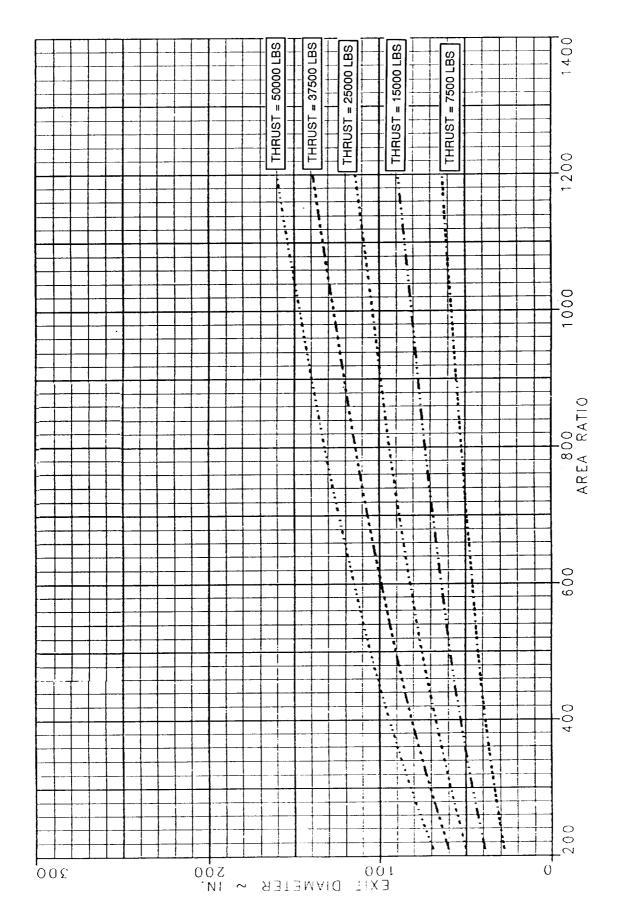
Exhaust Nozzle Exit Diameter Versus Thrust for Chamber Pressure = 1500 psia Figure 65.



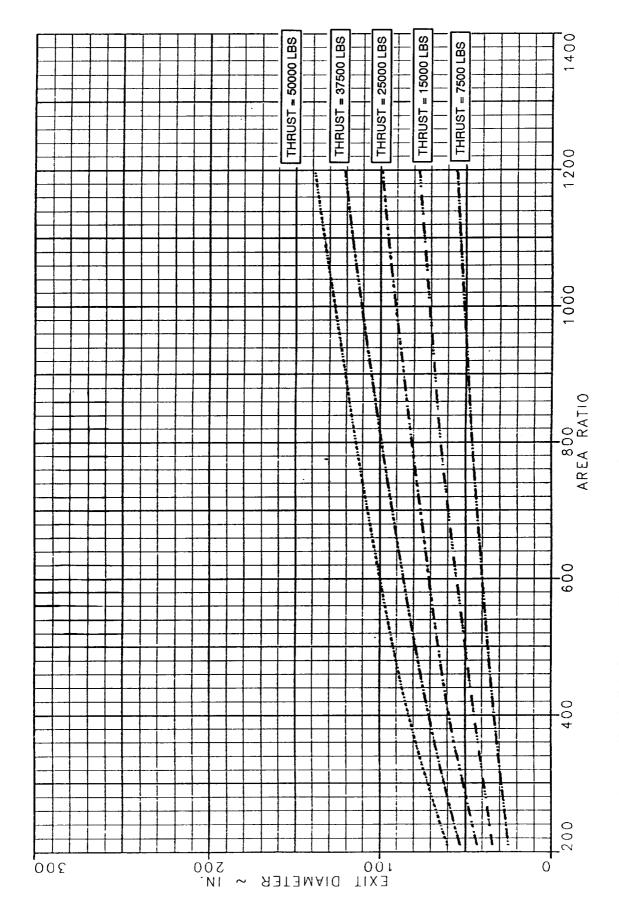
Exhaust Nozzle Exit Diameter Versus Thrust for Chamber Pressure = 2000 Figure 66.



Exhaust Nozzle Exit Diameter Versus Area Ratio for Chamber Pressure = 1000 psia Figure 67.



Exhaust Nozzle Exit Diameter Versus Area Ratio for Chamber Pressure = 1500 psia Figure 68.



Exhaust Nozzle Exit Diameter Versus Area Ratio for Chamber Pressure = 2000 psia Figure 69.

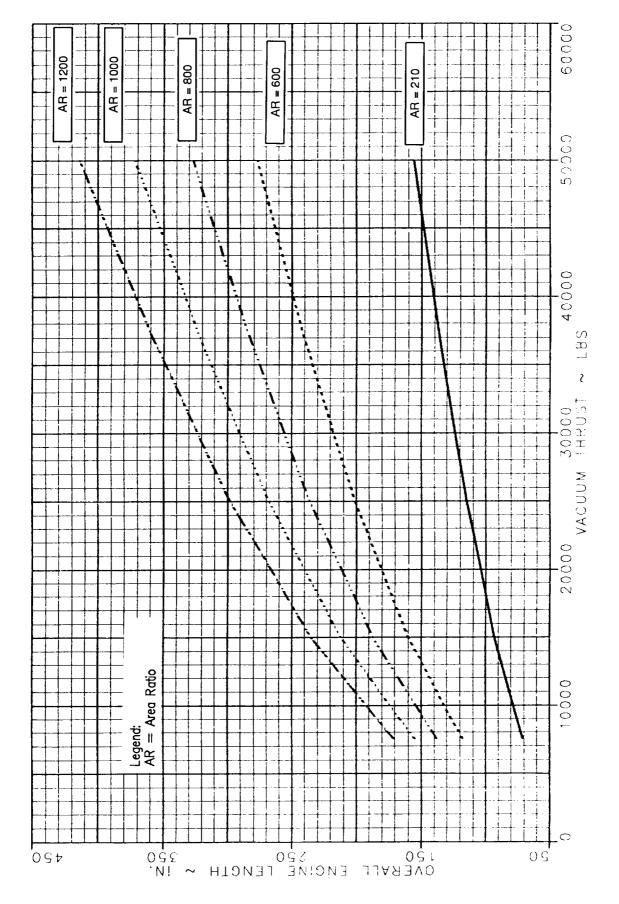


Figure 70. Engine Length Versus Thrust for Chamber Pressure = 1000 psia

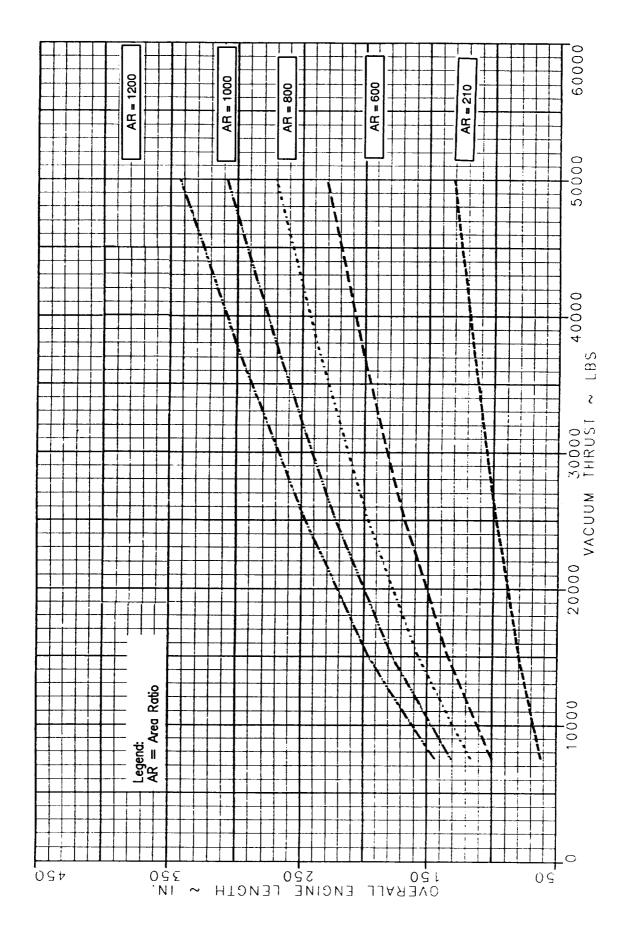


Figure 71. Engine Length Versus Thrust for Chamber Pressure = 1500 psia

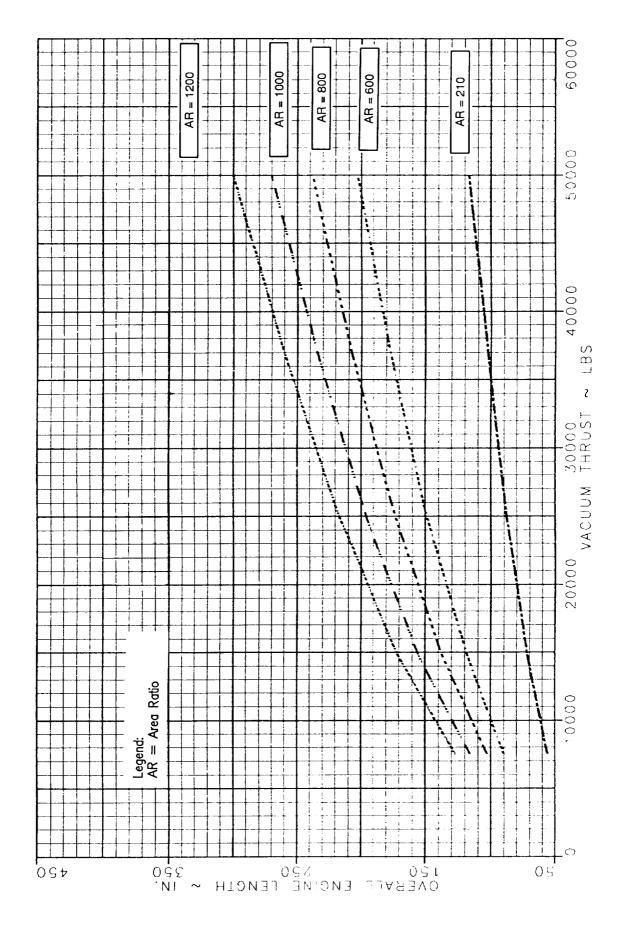


Figure 72. Engine Length Versus Thrust for Chamber Pressure = 2000 psia

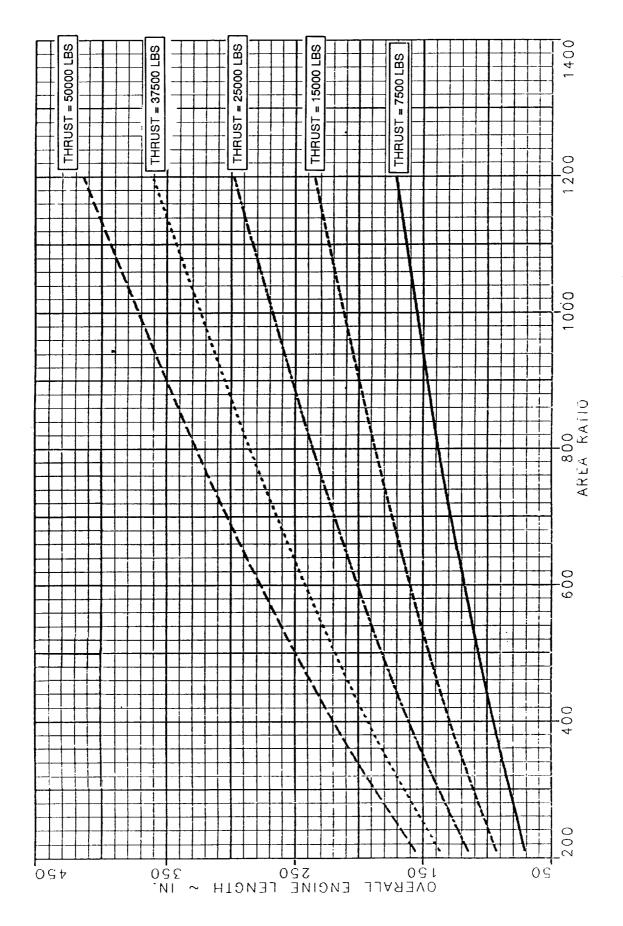
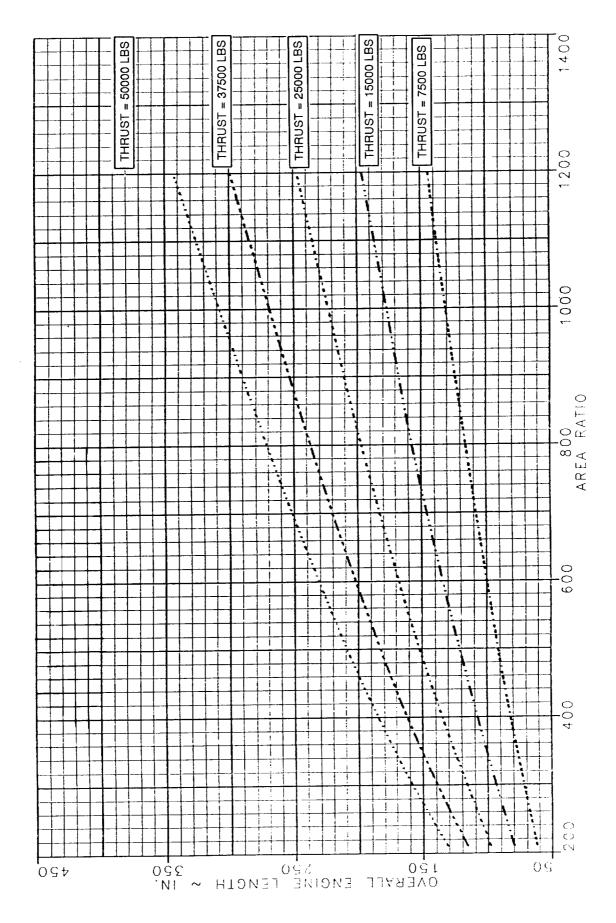
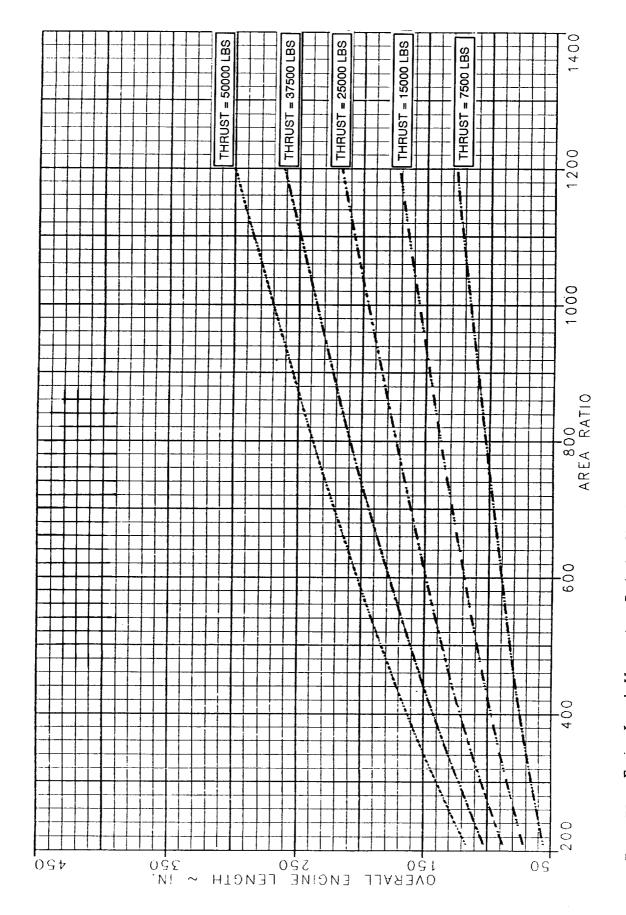


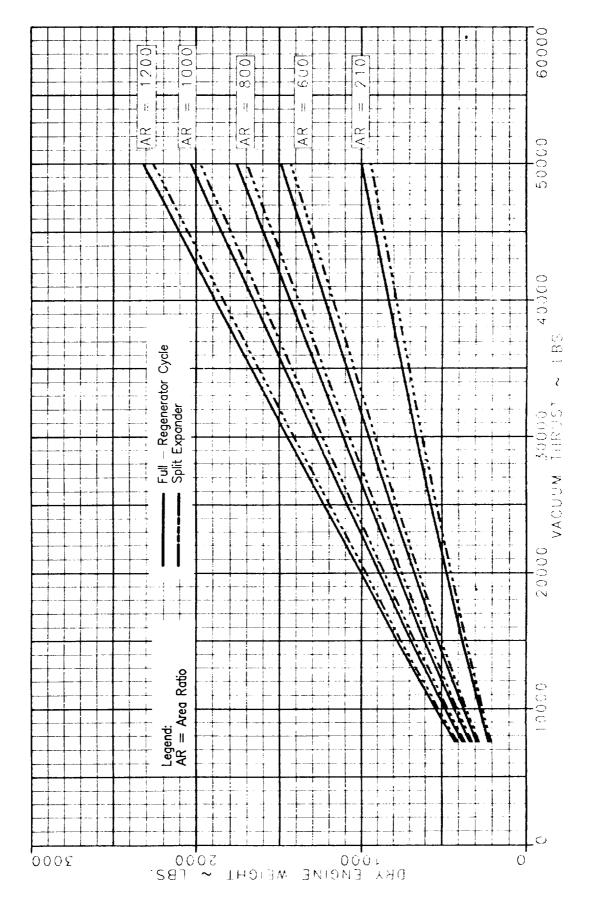
Figure 73. Engine Length Versus Area Ratio for Chamber Pressure = 1000 psia



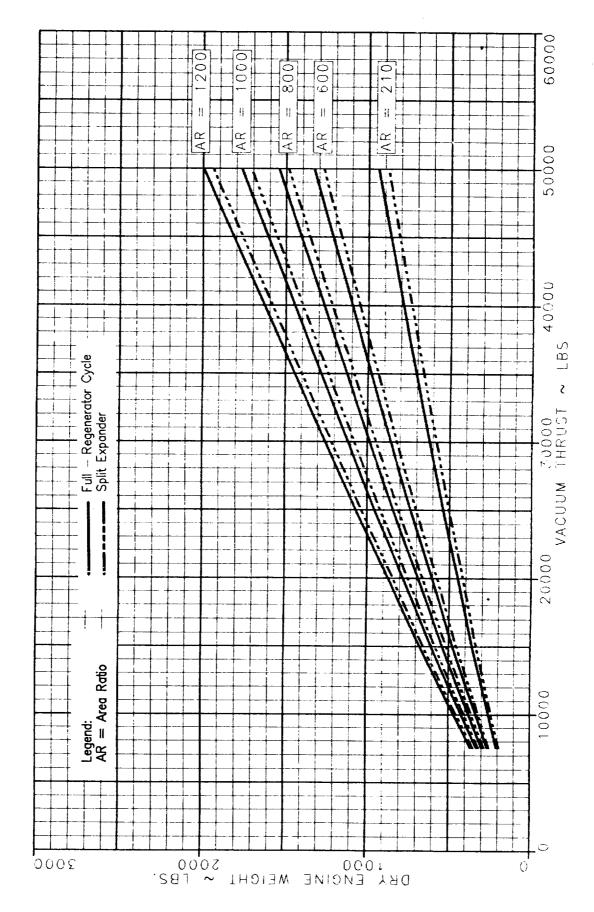
Engine Length Versus Area Ratio for Chamber Pressure = 1500 psia Figure 74.



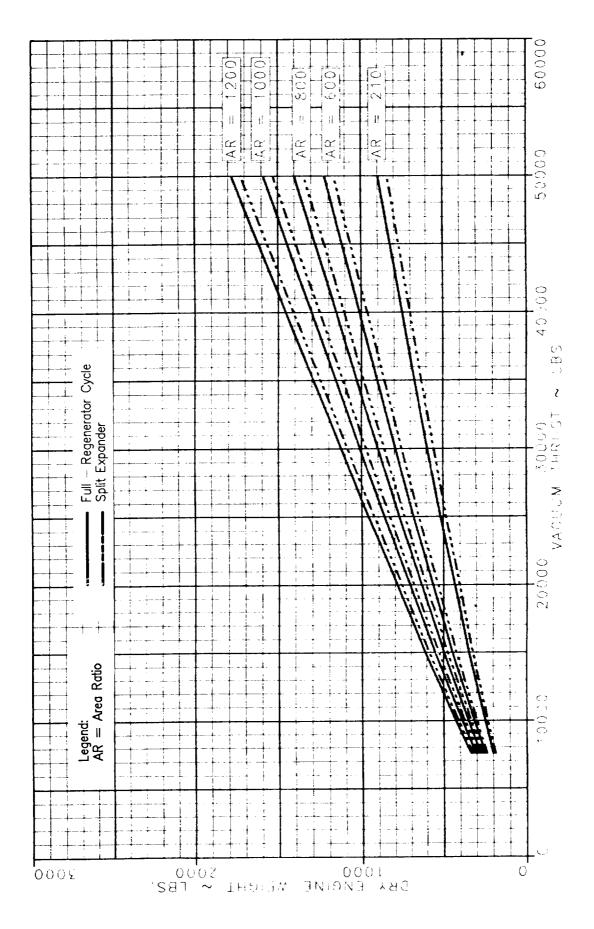
Engine Length Versus Area Ratio for Chamber Pressure = 2000 psia Figure 75.



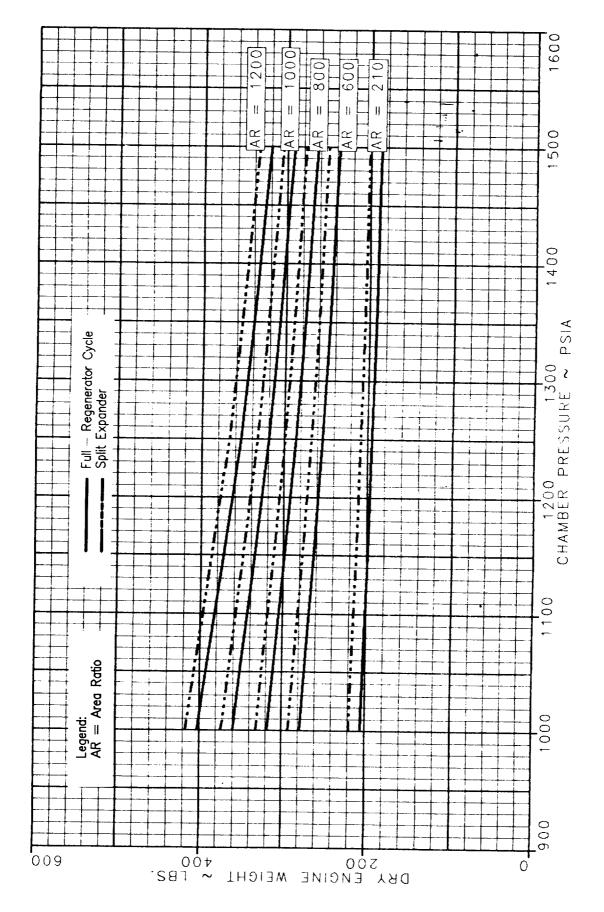
Parametric Engine Dry Weight Data for Chamber Pressure = 1000 psia Figure 76.



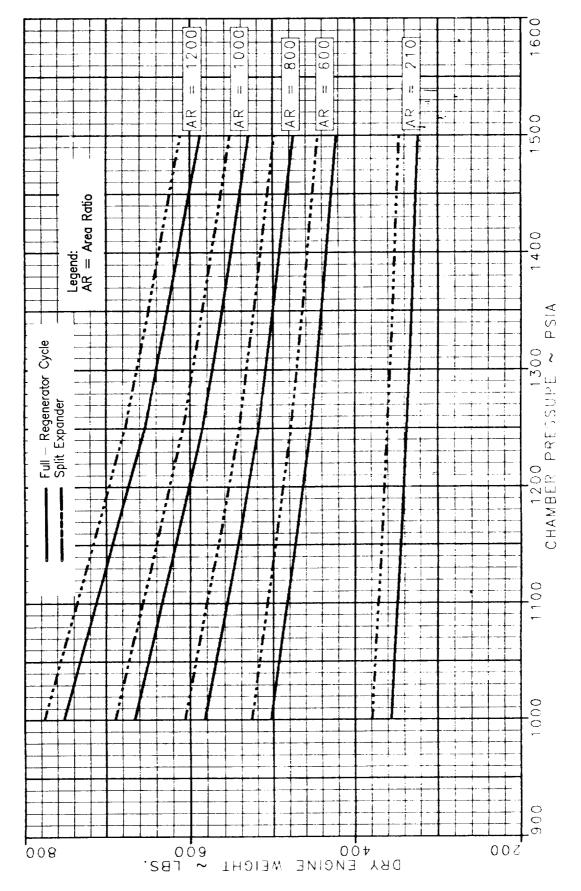
Parametric Engine Dry Weight Data for Chamber Pressure = 1250 psia Figure 77.



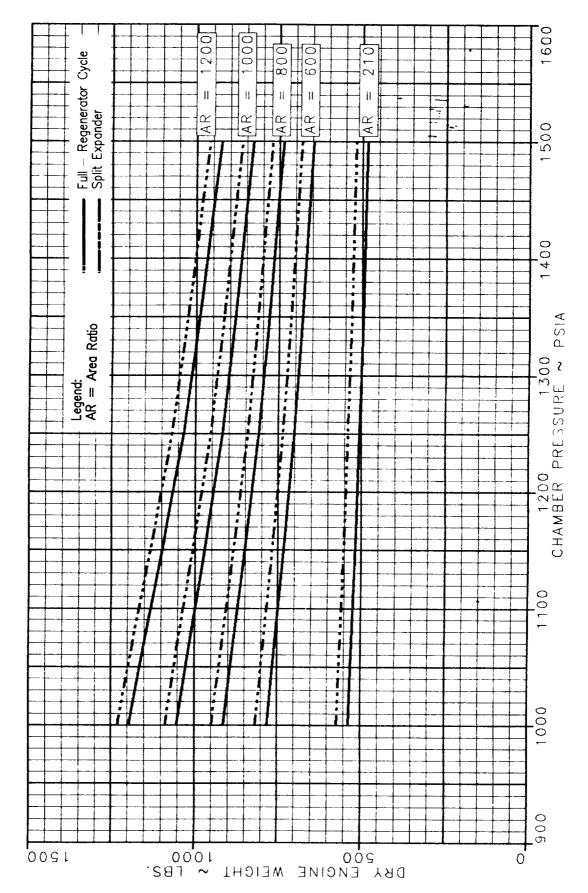
Parametric Engine Dry Weight Data for Chamber Pressure = 1500 psia Figure 78.



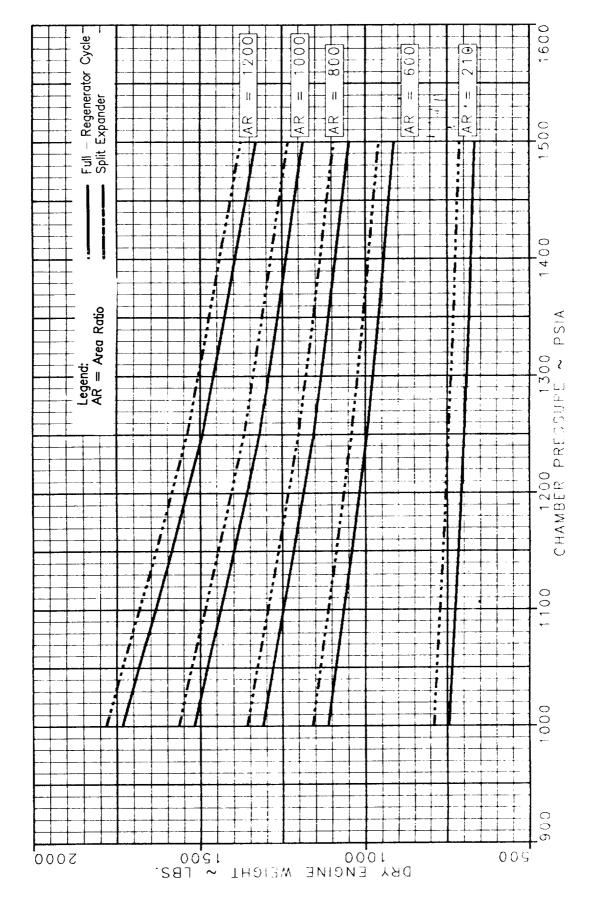
Parametric Engine Dry Weight Data for Vacuum Thrust = 7500 pounds Figure 79.



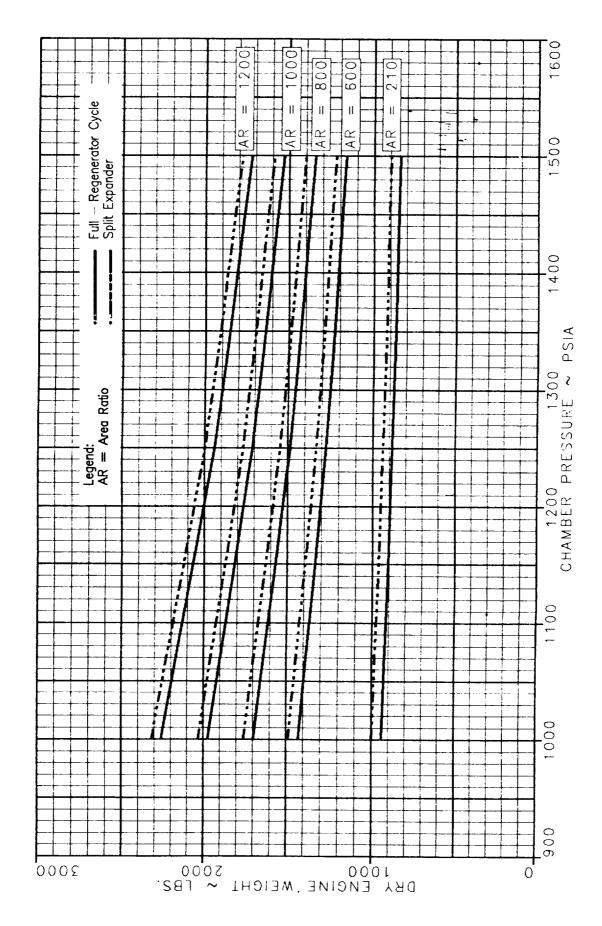
Parametric Engine Dry Weight Data for Vacuum Thrust = 15,000 pounds Figure 80.



Parametric Engine Dry Weight Data for Vacuum Thrust = 25,000 pounds Figure 81.



Parametric Engine Dry Weight Data for Vacuum Thrust = 37,500 pounds Figure 82.



Parametric Engine Dry Weight Data for Vacuum Thrust = 50,000 pounds Figure 83.

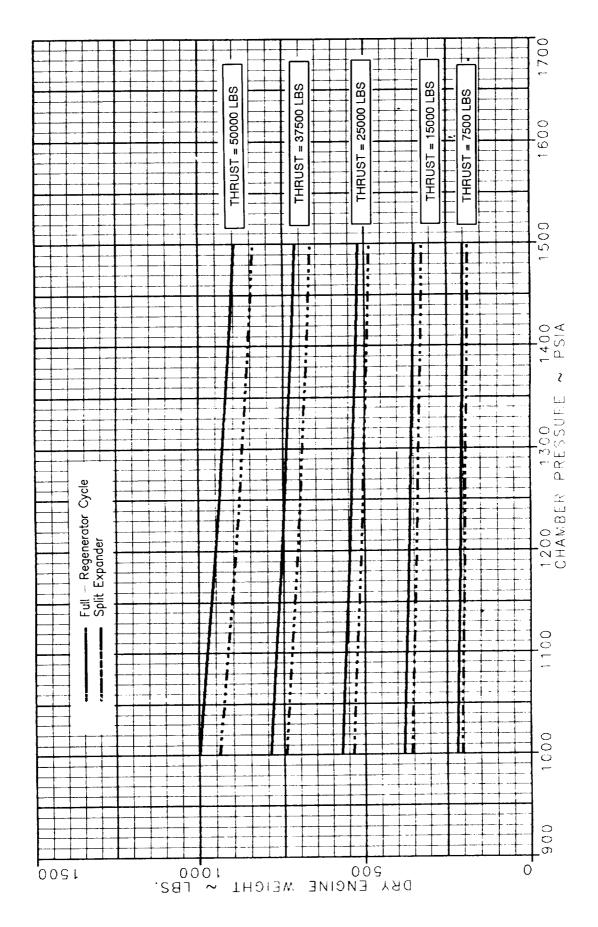


Figure 84. Parametric Engine Dry Weight Data for Area Ratio = 210

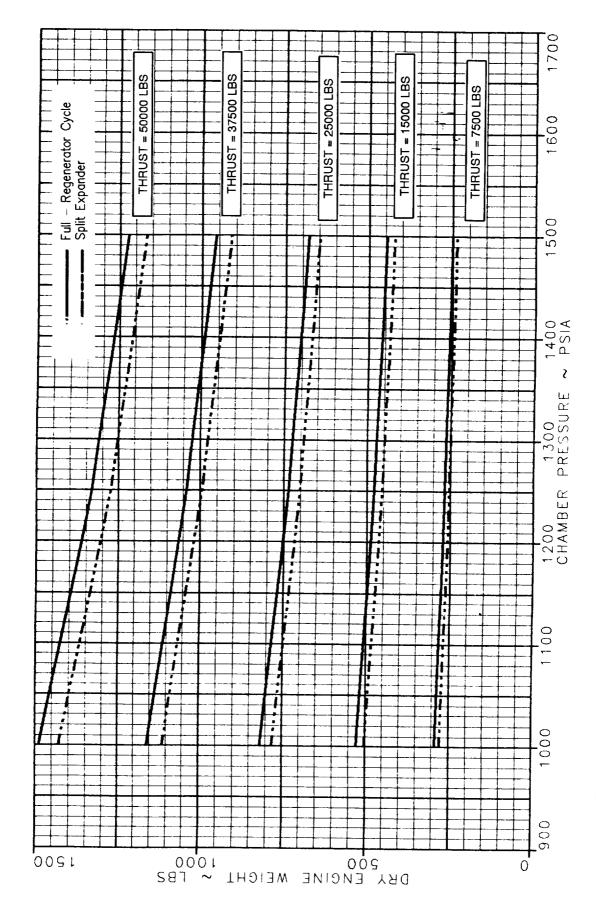
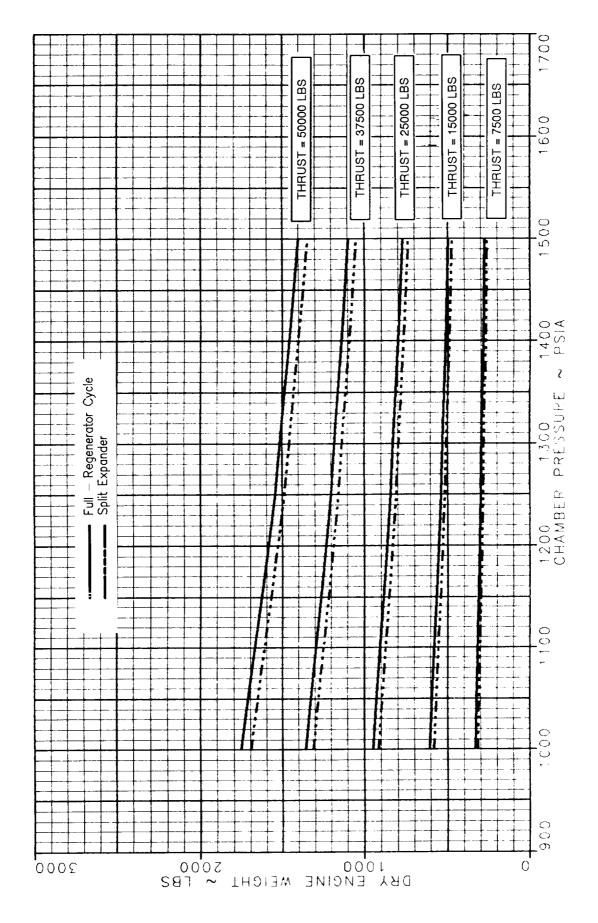


Figure 85. Parametric Engine Dry Weight Data for Area Ratio = 600



Parametric Engine Dry Weight Data for Area Ratio = 800 Figure 86.

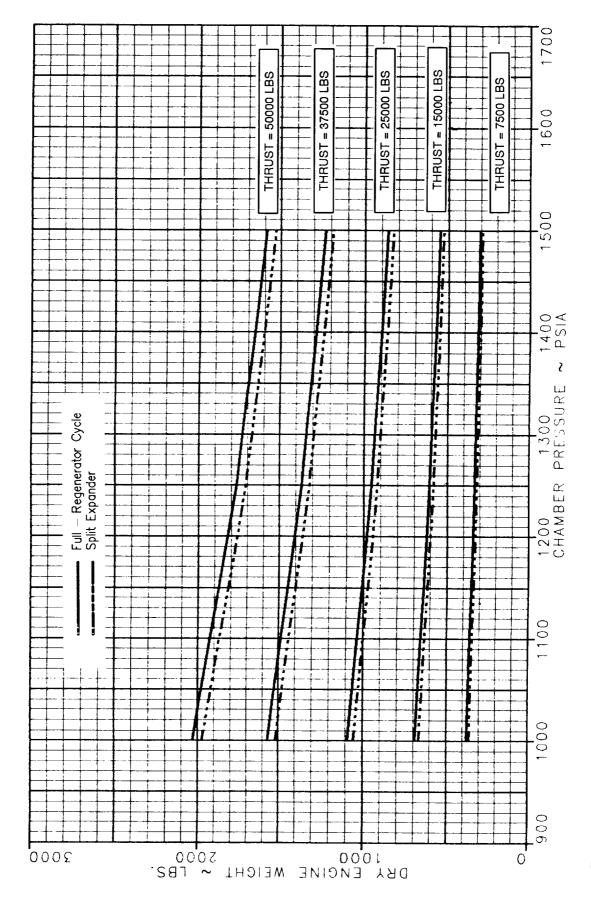


Figure 87. Parametric Engine Dry Weight Data for Area Ratio = 1000

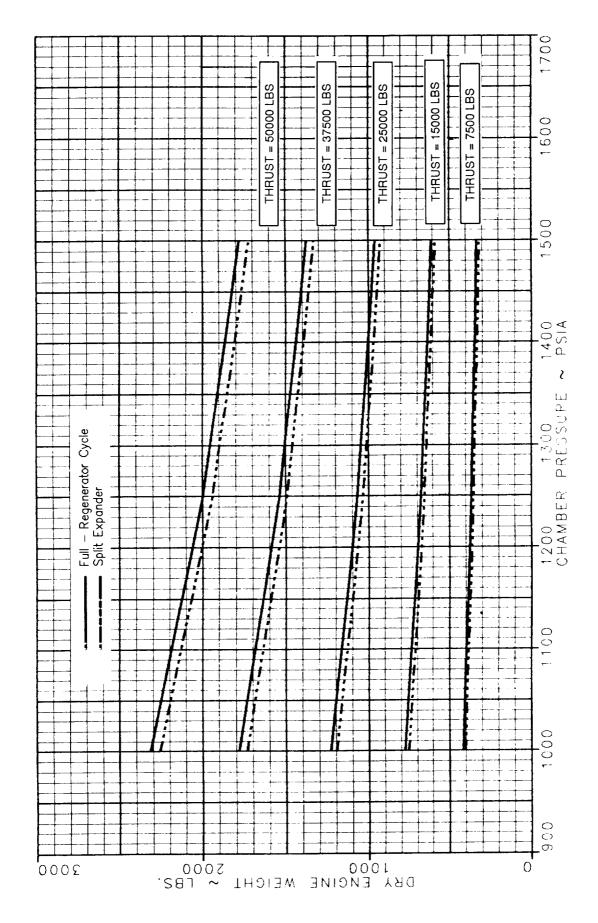


Figure 88. Parametric Engine Dry Weight Data for Area Ratio = 1200

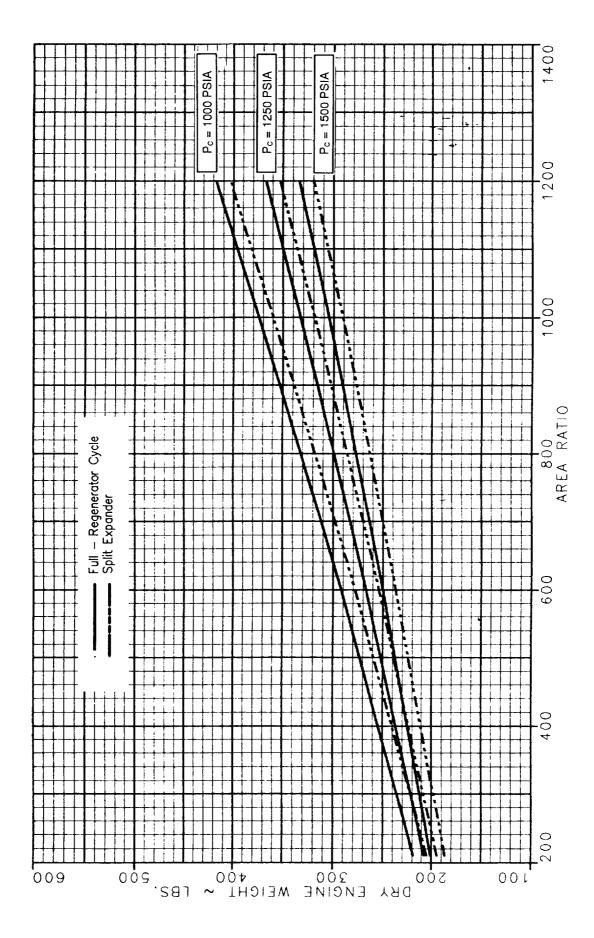


Figure 89. Parametric Engine Dry Weight Data for Thrust = 7500 lb

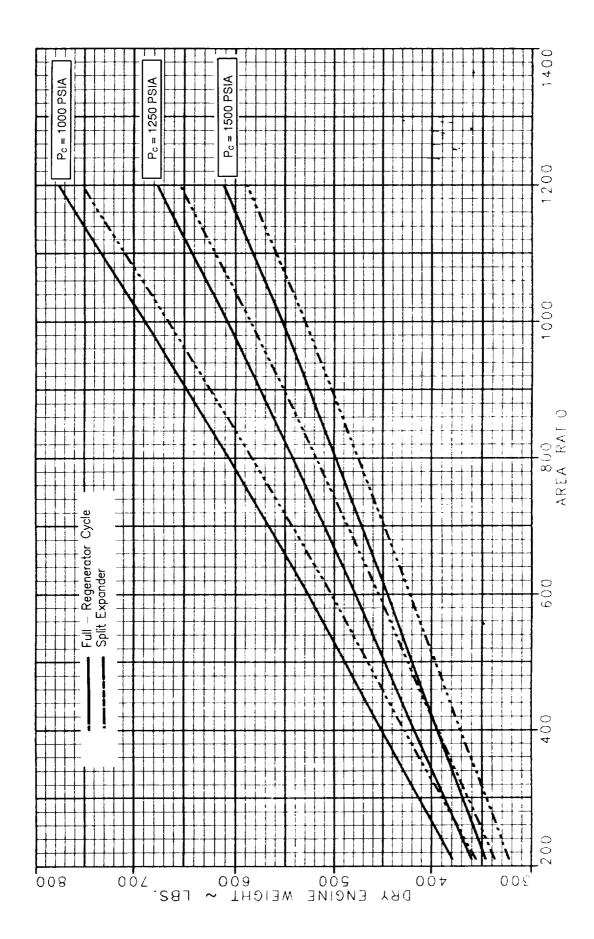


Figure 90. Parametric Engine Dry Weight Data for Thrust = 15,000 lb

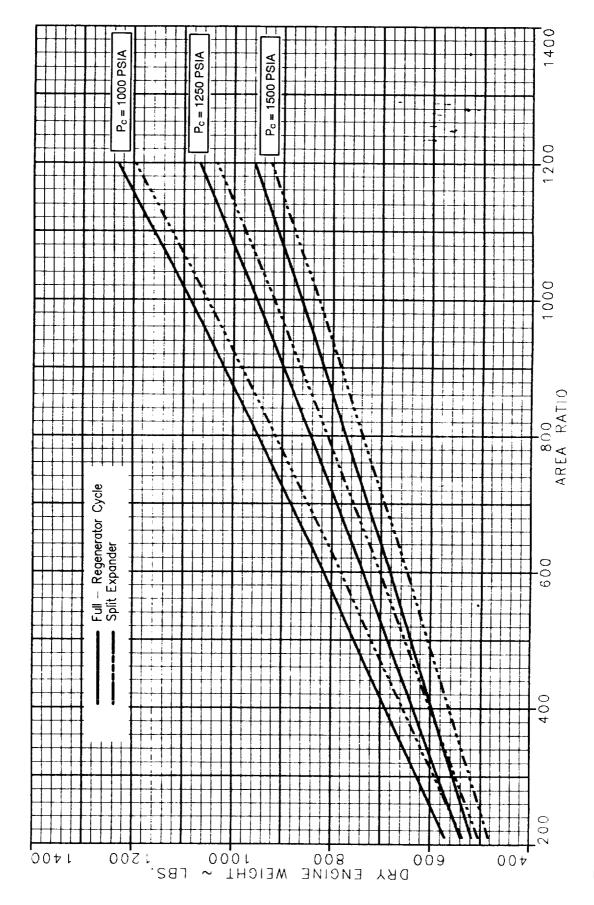


Figure 91. Parametric Engine Dry Weight Data for Thrust = 25,000 lb

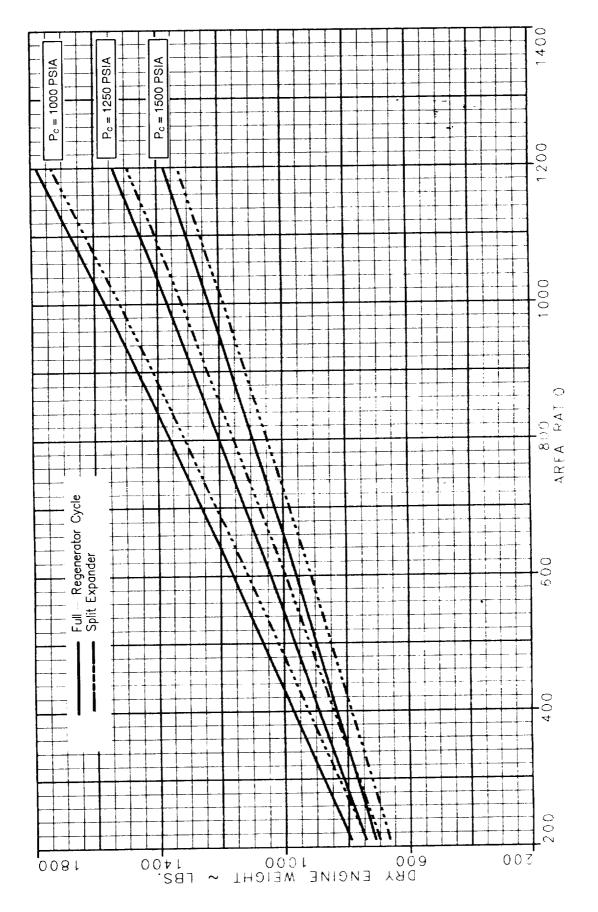


Figure 92. Parametric Engine Dry Weight Data for Thrust = 37,500 lb

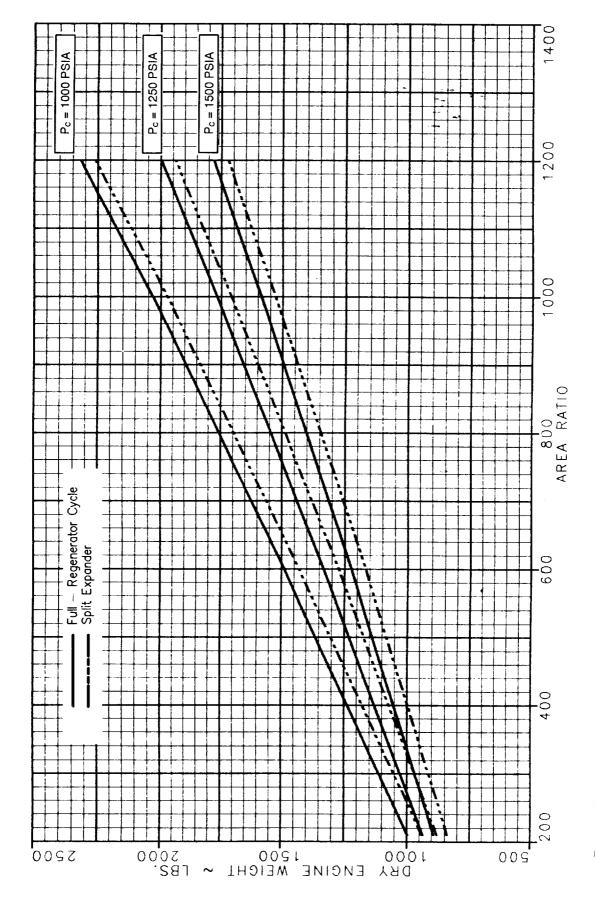
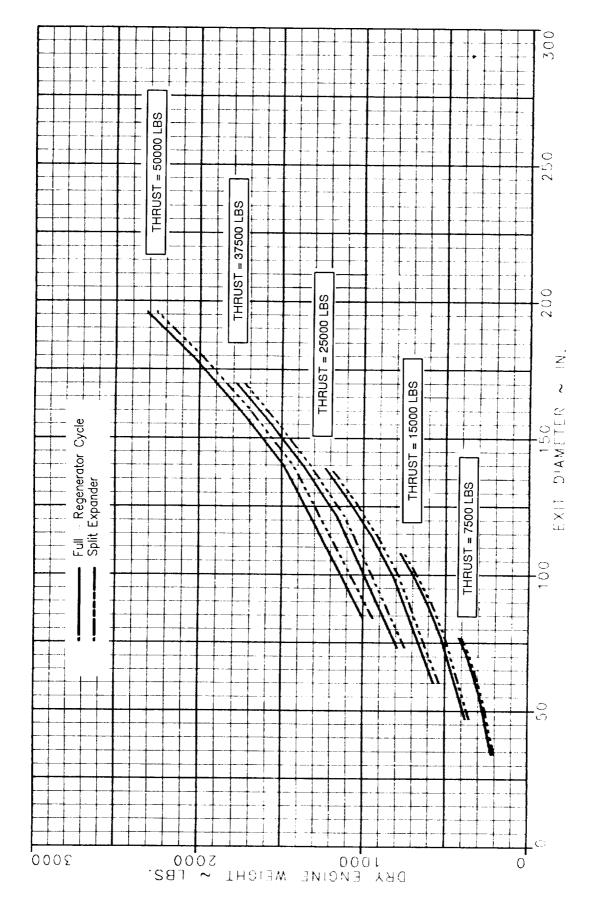


Figure 93. Parametric Engine Dry Weight Data for Thrust = 50,000 lb



Parametric Engine Dry Weight Data for Chamber Pressure = 1000 psia Figure 94.

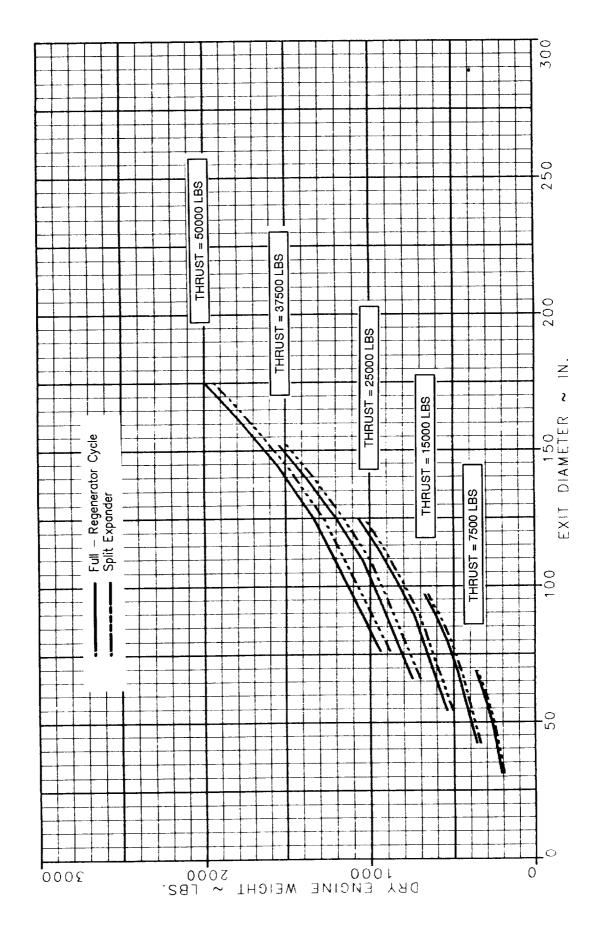
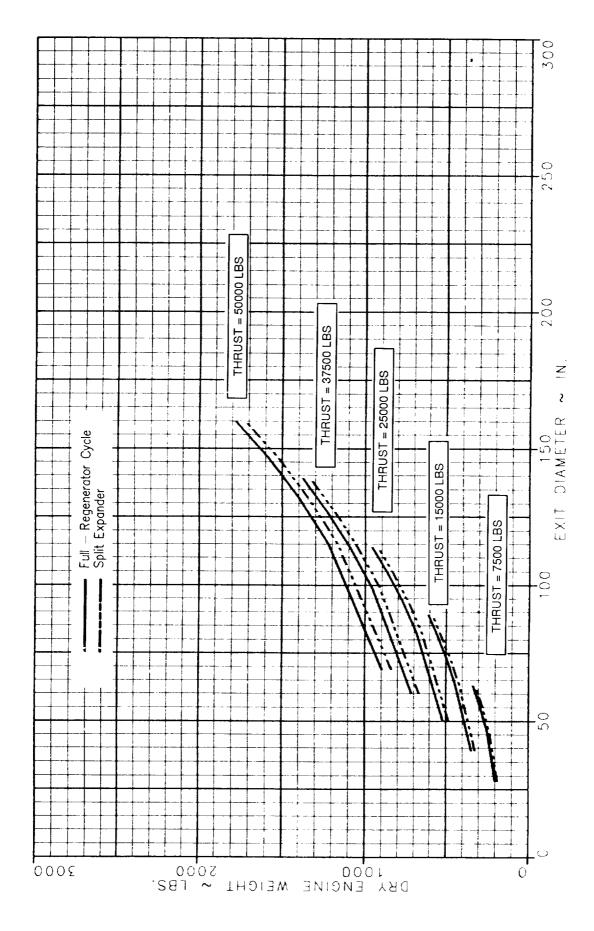
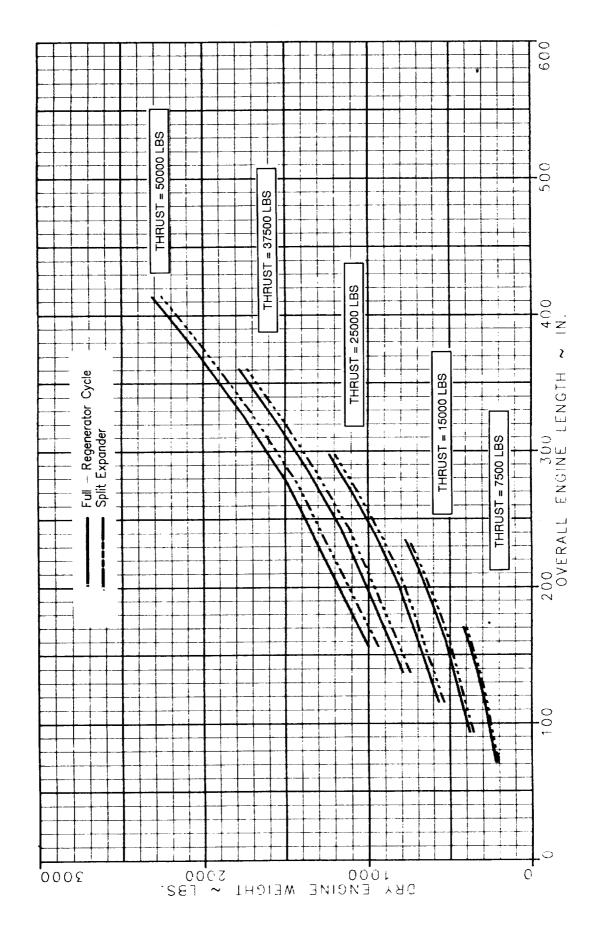


Figure 95. Parametric Engine Dry Weight Data for Chamber Pressure = 1250 psia



Parametric Engine Dry Weight Data for Chamber Pressure = 1500 psia Figure 96.



Parametric Engine Dry Weight Data for Chamber Pressure = 1000 psia Figure 97.

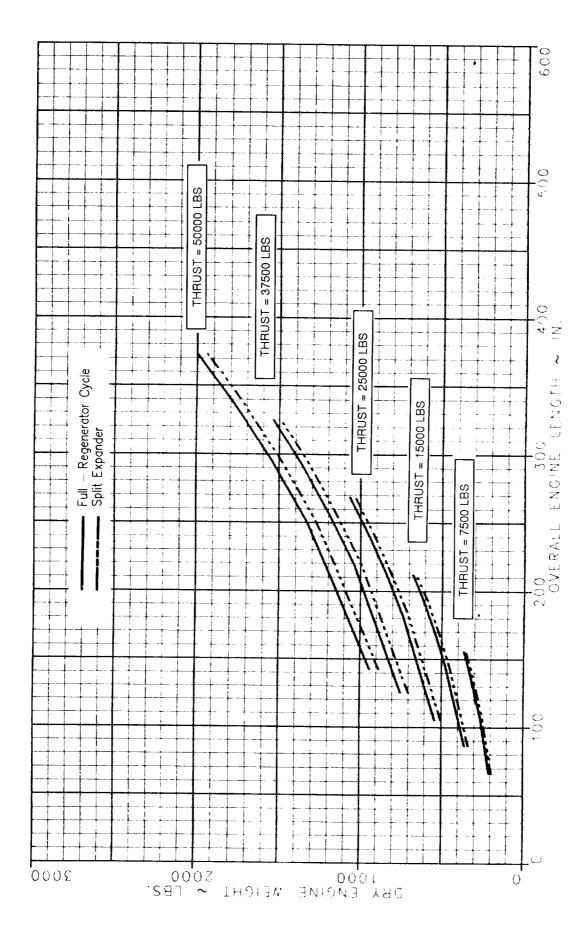


Figure 98. Parametric Engine Dry Weight Data for Chamber Pressure = 1250 psia

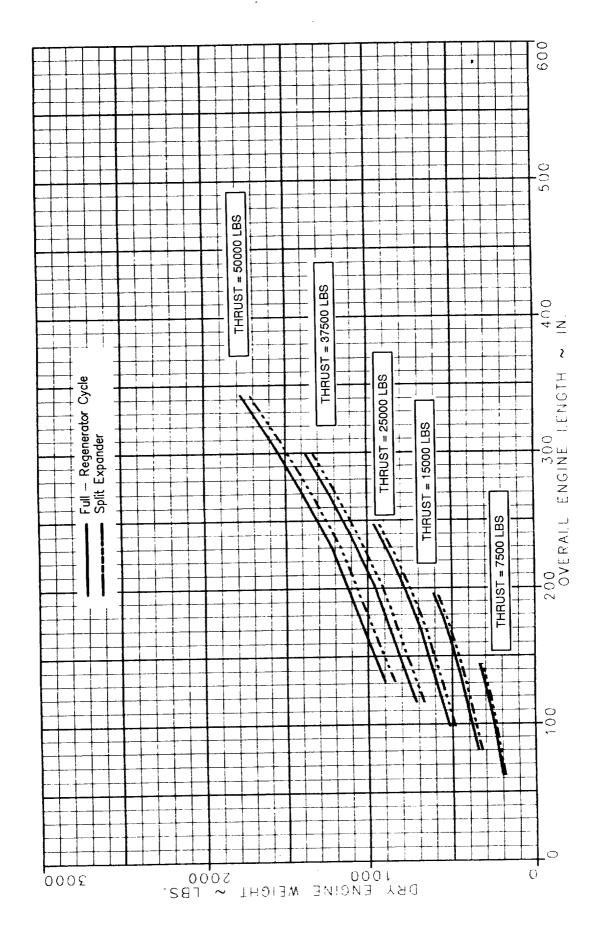
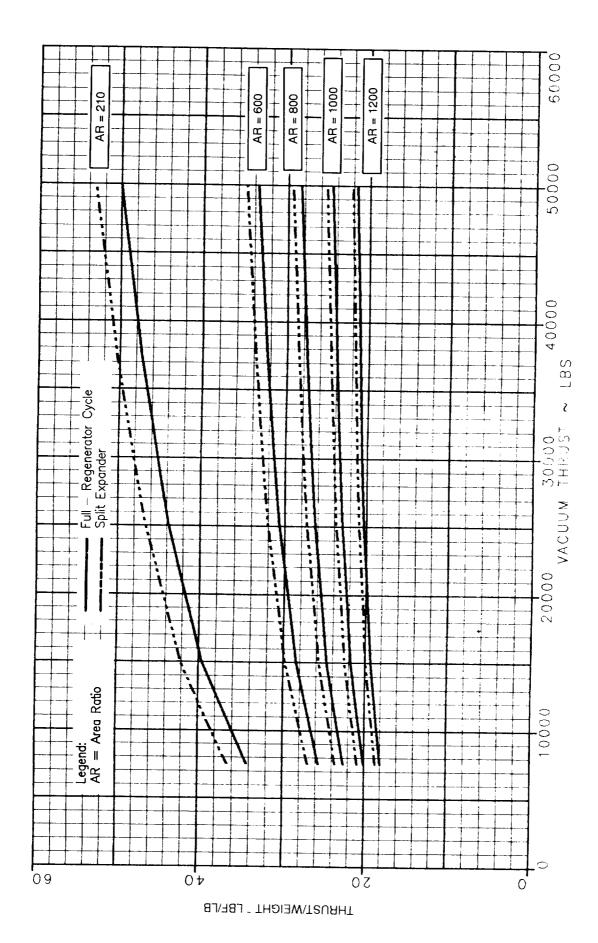


Figure 99. Parametric Engine Dry Weight Data for Chamber Pressure = 1500 psia



Parametric Engine Dry Weight Data for Chamber Pressure = 1000 psia Figure 100.

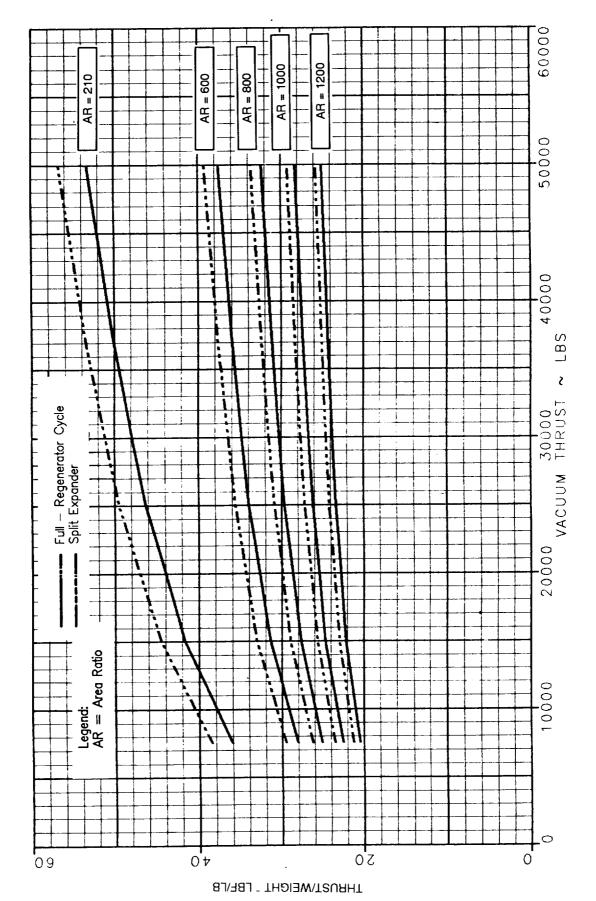
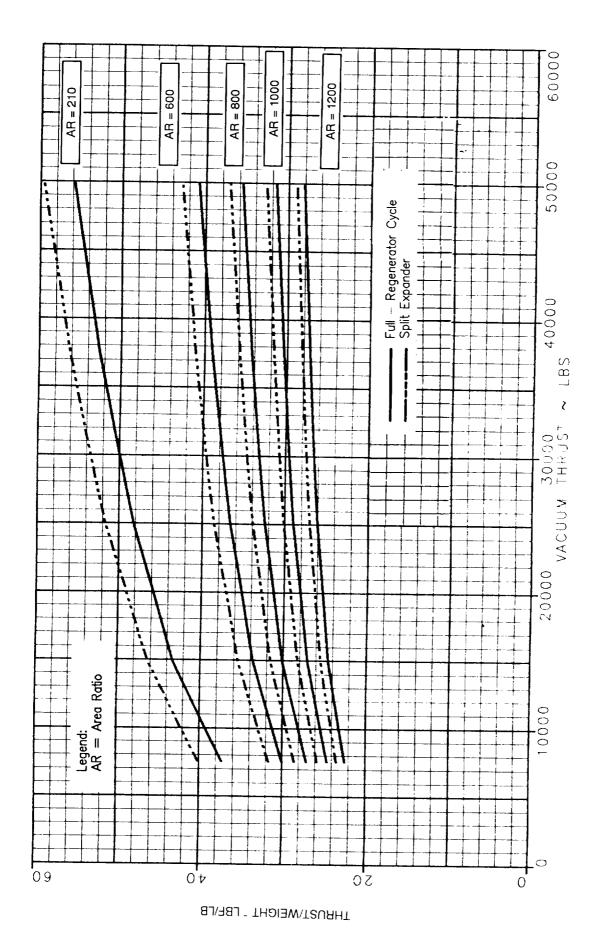


Figure 101. Parametric Engine Dry Weight Data for Chamber Pressure = 1250 psia



Parametric Engine Dry Weight Data for Chamber Pressure = 1500 psia Figure 102.

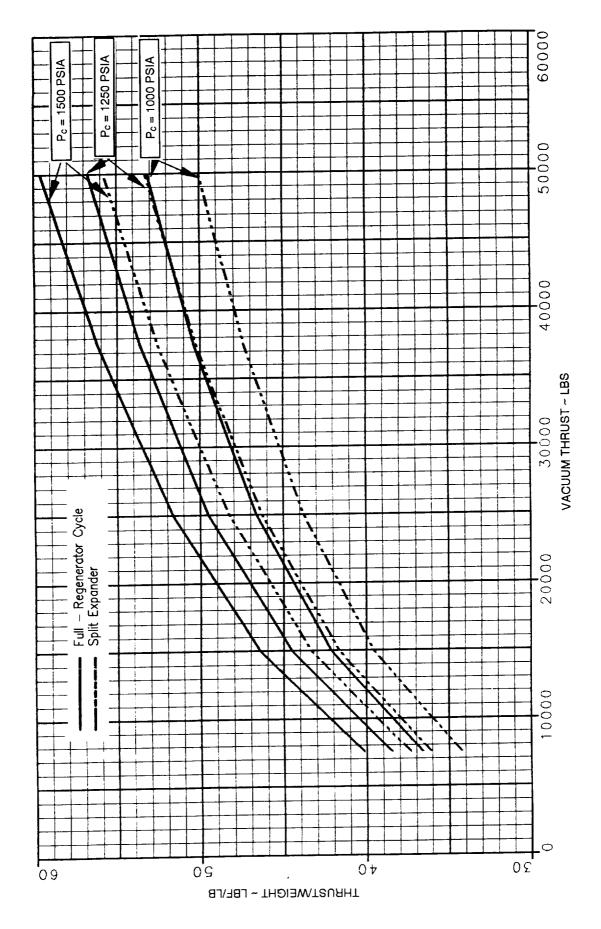


Figure 103. Parametric Engine Dry Weight Data for Area Ratio = 210

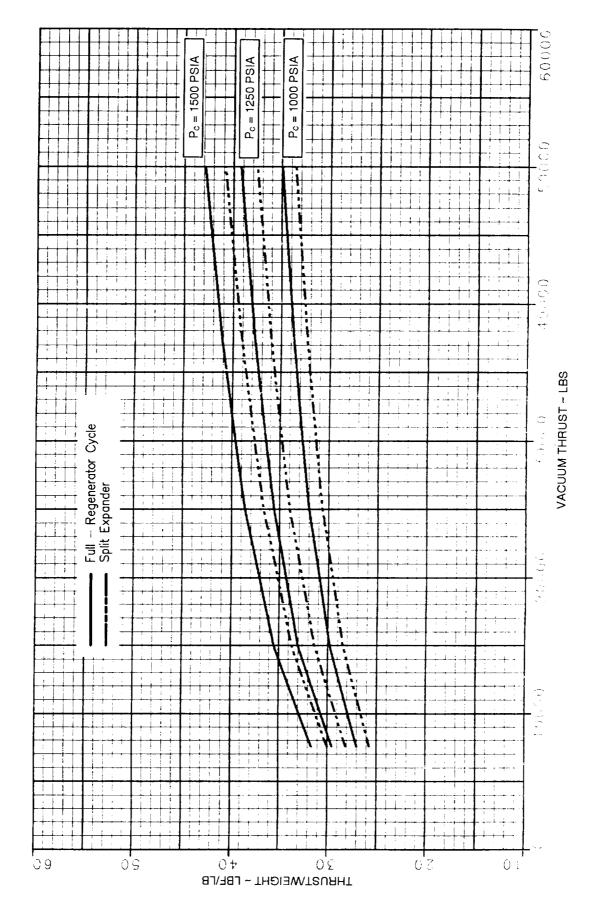


Figure 104. Parametric Engine Dry Weight Data for Area Ratio = 600

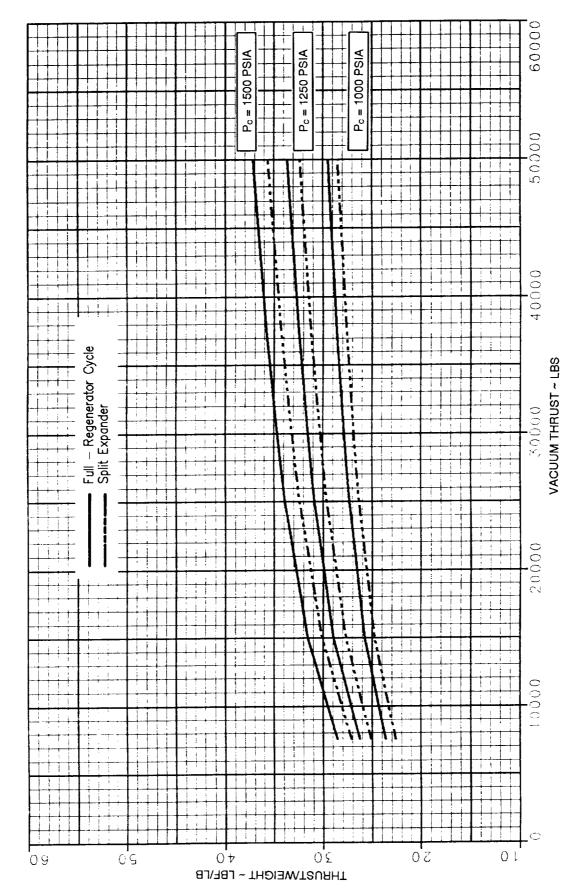


Figure 105. Parametric Engine Dry Weight Data for Area Ratio = 800

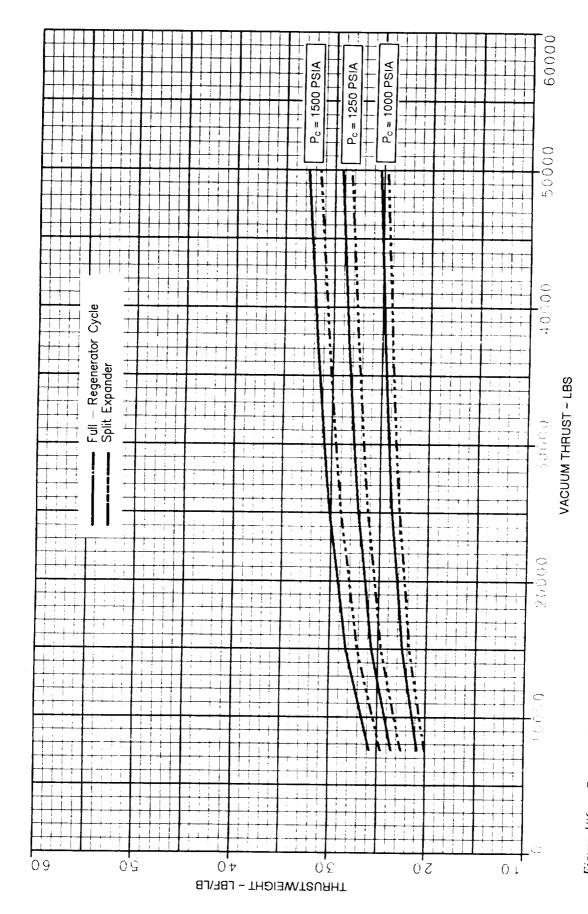


Figure 106. Parametric Engine Dry Weight Data for Area Ratio = 1000

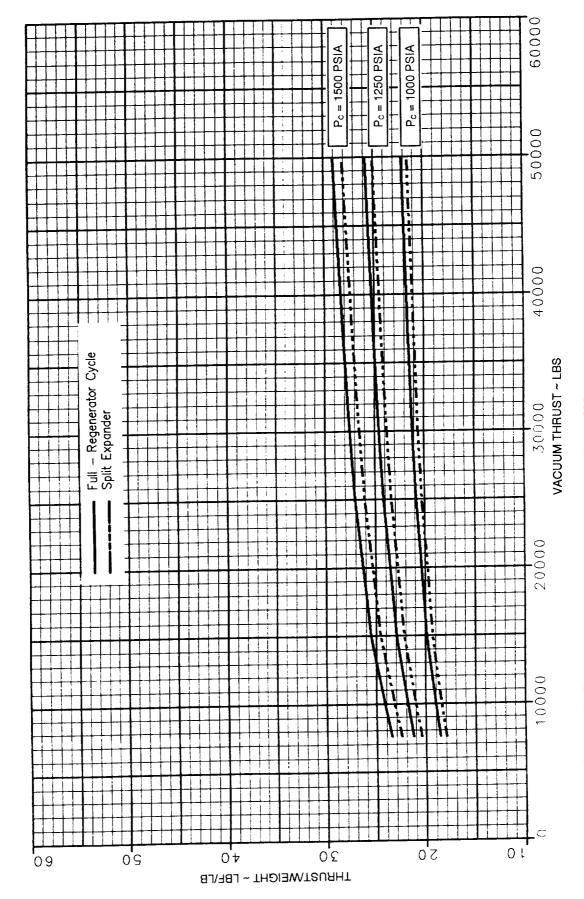


Figure 107. Parametric Engine Dry Weight Data for Area Ratio = 1200

## APPENDIX B FULL-THRUST CYCLES

Full-thrust cycle data are presented in Tables 9 through 48.

## TABLE 9. — FULL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER)

#### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1862.5 |
|------------------------|--------|
| VAC ENGINE THRUST      | 7500.  |
| TOTAL ENGINE FLOW RATE | 15.62  |
| DEL. VAC. ISP          | 480.1  |
| THROAT AREA            | 1.97   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 50.10  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C.                 | 0.993  |
| CHAMBER COOLANT DP     | 791.   |
| CHAMBER COOLANT DT     | 785.   |
| NOZZLE/CHAMBER Q       | 6571.  |

|                                 | ■ FUEL  | SYSTEM CON     | ADITIONS =   |                  |              |
|---------------------------------|---------|----------------|--------------|------------------|--------------|
| STATION                         | PRESS   |                |              | ENTHALPY         | DENSITY      |
| B.P. INLET                      | 18.6    | 37.4           | 2.23         | -107.5           | 4.37         |
| B.P. EXIT                       | 100.4   | 38.5           | 2.23         | -103.0           | 4.39         |
| PUMP INLET                      | 100.4   | \$8.5          | 2.23         | -103.0           | 4.39         |
|                                 | 1896.8  | 69.3           | 2.23         | 24.6             | 4.27         |
|                                 | 3618.5  | 69.3<br>97.8   | 2.23         | 146.9            | 4.25         |
| PUMP EXIT                       | 5287.6  | 124.3          | 2.23         | 264.1            | 4.28         |
| COOLANT INLET                   | 5234.8  | 124.7          | 2.23         | 264.1            | 4.26         |
| COOLANT EXIT                    | 4443.6  | 529.5          | 2.23         | 3205.3           | 0.82         |
| TBV INLET                       | 4399.1  | 909.8          | 0.11         | 3205.3           | 0.81         |
| TBV EXIT                        | 2084.4  | 925.6          | 0.11         | 3205.3           | 0.40         |
| 02 TRB INLET                    | 4399.1  | 909.8          | 2.12         | 3205.3           | 0.81         |
| O2 TRB EXIT                     | 4003.3  | 893.6          | 2.12         | 3138.4           | 0.76<br>0.76 |
|                                 | 4003.3  | B93.6          | 2.12         | 3138.4           | 0.75         |
| H2 TRB EXIT                     | 2209.2  | 796.1          | 2.12         | 2751.9           | 0.48         |
| H2 TRB DIFFUSER                 |         | 796.3          | 2.12         | 2751.9<br>2751.9 | 0.48         |
|                                 | 2160.2  | 796.3          | 2.12<br>2.12 | 2747.1           | 0.48         |
| H2 BST TRB OUT                  | 2141.2  | 795.2          | 2.12         | 2747.1           | 0.47         |
| H2 BST TRB DIFF                 |         | 795.3          | 2.12         | 2747.1           | 0.47         |
| 02 BST TRB IN<br>02 BST TRB OUT | 2104.9  | 795.4<br>794.8 | 2.12         | 2744.6           | 0.47         |
|                                 |         | 794.8          | 2.12         | 2744.6           | 0.47         |
| 02 BST TRB DIFF                 |         | 814.2          |              | 2767.6           | 0.0043       |
| H2 TANK PRESS GOX HEAT EXCH IN  |         | 801.4          | 2.23         | 2767.6           | 0.46         |
| GOX HEAT EXCH OU                |         | 801.0          | 2.23         | 2766.2           | 0.46         |
| FSOV INLET                      | 2073.9  | 801.0          | 2.23         | 2766.2           | 0.46         |
|                                 | 2022.1  | 801.4          | 2.23         | 2766.2           | 0.45         |
| FSOV EXIT<br>CHAMBER INJ        | 2001.8  | 801.5          | 2.23         |                  | 0.44         |
| CHAMBER                         | 1862.5  |                |              |                  |              |
|                                 |         |                |              |                  |              |
|                                 | # OYY6  | EN SYSTEM      | CONDITIONS   | s •              |              |
| STATION                         | PRESS   |                |              | ENTHALPY         | DENSITY      |
| B.P. INLET                      | 16.0    | 162.7          | 13.4         | 61.1             | 71.17        |
| B.P. EXIT                       | 135.6   | 163.2          | 13.4         | 61.5             | 71.20        |
| PUMP INLET                      | 135.6   | 163.2          | 13.4         | 61.5             | 71.20        |
| PUMP EXIT                       | 3016.3  | 178.2          | 13.4         | 72.1             | 71.52        |
| D2 TANK PRESS                   |         | 400.0          | 0.023        | 204.7            | 0.12         |
| OCV INLET                       | 2986.2  | 178.3          | 13.4         | 72.1             | 71.47        |
| OCV EXIT                        | 2090.3  | 181.8          | 13.4         | 72.1             | 70.08        |
| CHAMBER INJ                     | 2048.7  | 182.0          | 13.4         | 72.1             | 70.02        |
| CHAMBER                         | 1862.5  |                |              |                  |              |
|                                 |         |                |              |                  |              |
|                                 |         | VALVE DA       |              |                  |              |
| VALVE                           | DELTA P | AREA           | FLOW         | % BYPASS         |              |
| TBV                             | 2315.   | 0.01           | 0.11         | 5.00             |              |
| FSOV                            | 52.     | 0.67           |              |                  |              |
| OCV                             | 896.    | 0.08           | 13.39        |                  |              |
|                                 |         |                |              |                  |              |
|                                 |         | INJECTOR       |              |                  |              |
| INJECTOR                        | DELTA P |                |              | VELOCITY         |              |
| FUEL                            | 139.    | 0.47           |              | 1569.64          |              |
| LOX                             | 207.    | 0.18           | 13.39        | 156.98           |              |

TABLE 9. — FULL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|   | ***************************************  |
|---|--|
|   | NERY PERFORMANCE DATA =  |
| *************   | ***********  |
| P H2 BOOST TURBINE D  | F H2 BOOST PUMP +  |
|   |  |
| EFFICIENCY (T/T) 0.487<br>EFFICIENCY (T/S) 0.333                        | EFFICIENCY 8,766 HORSEPOWER 14.  |
| SPEED (RPM) 75325,<br>MEAN DIA (IN) 0.82                                | SPEED (RPH) 75325.   |
| EFF AREA (IM2) 1.03   | S SPEED 3049,<br>HEAD (FT) 2688.<br>DIA. (IH) 1.33   |
| U/C (ACTUAL) 0.553<br>MAX TIP SPEED 370.                                | DIA. (IN) 1.33<br>TIP SPEED 438.   |
| STAGES 1  | VALUE OF THE STATE |
| PRESS RATIO (T/T) 1.01  | HEAD COEF 0.450<br>FLOH COEF 0.201   |
| PRESS RATIO (T/S) 1.82<br>HORSEPOHER 14.                                |  |
| EXIT MACH NUMBER A 10   |  |
| SPECIFIC SPEED 143.05<br>SPECIFIC DIMETER 0.50                          |  |
|   |  |
| F4817481111999  | *********  |
| = M2 TURBINE =  | e H2 Pump n<br>menananana  |
|   | STAGE ONE STAGE THO STAGE THREE  |
| EFFICIENCY (T/T) 0.80)  | EFFICIENCY 0.605 0.612 0.617<br>HORSEPONER 404. 386. 371.  |
| EFFICIENCY (T/T) 0.801<br>EFFICIENCY (T/S) 0.781<br>SPEED (RPH) 187500. | HORSEPOMER 404. 384. 371.<br>SPEED (RPH) 187500. 187500. 187500.<br>SS SPEED 9332.   |
| HORSEPOHER 1161.  | 33 SPEED 9352.   |
| HORSEPOMER 1161. MEAN DIA. (IN) 1.62 EFF AREA (IN2) 0.11                | SPEED (RPH) 187508. 187500. 187500.  SS SPEED 9352. S SPEED 769. 768. 795.  HEAD (FT) 60127. 58236. 56326. DIA. (IM) 2.35 2.35 2.35 TIP SPEED 1925. 1926. 1925.  |
| U/C (ACTUAL) 0.521<br>MAX TIP SPEED 1434.                               | DIA. (IN) 2.35 2.35 2.35<br>TIP SPEED 300  |
| MAX TIP SPEED 1436.<br>STAGES 3   |  |
| GAMMA 1.38<br>PRESS RATIO (T/T) 1.81                                    | HEAD COCF 4.522 0.506 0.489<br>FLOM COCF- 0.093  |
| PRESS RATIO (T/S) L.B4  | DIAMETER RATIO 8.315   |
|   | BEARING DN 3.00E+96<br>SMAFT DIAMETER 16.00  |
| SPECIFIC DIAMETER 1.39  |  |
| *************   | ************   |
| * 02 BOOST TURBINE #  | # 02 BOOST PURP #  |
|   | ***************************************  |
| EFFICIENCY (T/T) 0.804<br>EFFICIENCY (T/S) 0.655                        | EFFICIENCY 0.764 HORSEPOIER 0.   |
| SPEED (RPM) 20104.<br>HEAN DIA (IN) 2.25                                | SPEED (RPH) 20184.   |
| EFF AREA (IN2) 1.54   | S SPEED 3026.<br>HEAD (FT) 242.<br>DIA. (IN) 1.49  |
| U/C (ACTUAL) 0.553<br>MAX TIP SPEED 238,                                |  |
| 21MG2 ]   | VOL. FLON BS.  |
| GAMMA 1.38<br>PRESS RATIO (T/T) 1.00                                    | HEAD COOF 9,450<br>FLON COOF 9,200   |
| PRESS RATIO (T/S) 1.01 HORSEPOWER R                                     |  |
| ERIT HACH NUMBER 0.85   |  |
| SPECIFIC SPEED 101.67<br>SPECIFIC DIAMETER 0.81                         |  |
|   |  |
| = 02 TURBINE =  | **********   |
| PROFESSOR OF STREET   | * 02 PUMP *  |
| EFFICIENCY (T/T) 0.803  | FFF ICIDARY A TAX  |
| EFFICIENCY (T/S) 0.753<br>SPEED (RPM) 130652.                           | EFF ICIENCY 0.703<br>MORSEPOMER 201.<br>SPEED (RPH) 130652.<br>SS. SPFFB 2348)   |
| HORSEPOHER 201.   | SPEED (RPH) 130652.<br>SS SPEED 23481.   |
| HORSEPOHER 201. MEAN DIA (IN) 1.42 EFF AREA (IN2) 0.18                  | 9 20100  |
| U/C (ACTUAL) 0.503  | HEAD (FT) 5799, DIA. (IN) 1.18 TIP SPEED 675, VOL. ELIDN 64  |
| MAX TIP SPEED 994. STAGES 1. GAMMA 1.38                                 | TIP SPEED 675. VOL. FLON 84.   |
| ****  |  |
| PRESS RATIO (T/T) 1.10 PRESS RATIO (T/S) 1.11                           | HEAD COEF 0.410 FLOW COEF 0.154 DIAMETER RATIO 0.679   |
| EXIT MACH NUMBER 0.09   | BEARING IN 1 STEAM   |
| SPECIFIC DIMETER 1.48   | SWFT DIMETER 12.00   |
|   |  |

## TABLE 10. — FULL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER)

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1696.5 |
|------------------------|--------|
| VAC ENGINE THRUST      | 15000. |
| TOTAL ENGINE FLOH RATE | 31.25  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 4.32   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 74.21  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C                  | 0.993  |
| CHAMBER COOLANT DP     | 579.   |
| CHAMBER COOLANT DT     | 599.   |
| NOZZLE/CHAMBER Q       | 10185. |

| •                 |                  |                |              |                   |              |
|-------------------|------------------|----------------|--------------|-------------------|--------------|
|                   | a EINFI S        | SYSTEM CON     | DITIONS .    |                   |              |
| STATION           | PRESS            | TEMP           | FLOH         | ENTHALPY          | DENSITY      |
| B.P. INLET        | 18.6             | 37.4           | 4.47         | -107.5            | 4.37         |
| B.P. EXIT         | 100.6            | 38.5           | 4.47         | -103.0            | 4.39         |
| PLMP INLET        | 100.6            | 38.5           | 4.47         | -103.0            | 4.39         |
| IST STAGE EXIT    | 1843.1           | 64.7           | 4.47         | 10.4              | 4.38         |
| 2ND STAGE EXIT    | 3556.9           | 89.5           | 4.47         | 121.3             | 4.40         |
| PUMP EXIT         | 5250.8           | 113.0          | 4.47         | 229.5             | 4.46         |
| COOLANT INLET     | 5198.3           | 113.5          | 4.47         | 229.5             | 4.44         |
| COOLANT EXIT      | 4619.0           | 712.1          | 4.47         | 2508.0            | 1.06         |
| TBV INLET         | 4572.8           | 712.4          | 0.22         | 2508.0            | 1.05         |
| TBV EXIT          | 1898.6           | 729.1          | 0.22         | 2508.0            | 0.46         |
| 02 TRB INLET      | 4572.8           | 712.4          | 4.25         | 2508.0            | 1.05         |
| 02 TRB EXIT       | 4123.2           | 698.9          | 4.25         | 2449.6            | 0.98<br>0.98 |
| H2 TRB INLET      | 4123.2           | 698.9          | 4.25         | 2449.6            | 0.58         |
| H2 TRB EXIT       | 2026.9           | 613.0          | 4.25         | 2099.5            | 0.57         |
| HZ TRB DIFFUSER   | 1993.6           | 613.2          | 4.25         | 2099.5<br>2099.5  | 0.57         |
| H2 BST TRB IN     | 1973.7           | 613.2          | 4.25         | 2094.8            | 0.56         |
| H2 BST TRB OUT    | 1952.9           | 612.1          | 4.25         | 2094.8            | 0.56         |
| H2 BST TRB DIFF   | 1938.9           | 612.2          | 4.25<br>4.25 | 2094.8            | 0.55         |
| 02 BST TRB IN     | 1919.5           | 612.3          | 4.25         | 2092.2            | 0.55         |
| 02 BST TRB DUT    | 1909.6           | 611.6          | 4.25         | 2092.2            | 0.55         |
| 02 BST TRB DIFF   | 1908.1           | 611.6          | 0.0058       | 2113.0            | 0.0057       |
| HZ TANK PRESS     | 18.6             | 627.2<br>617.5 | 4.46         | 2113.0            | 0.54         |
| GOX HEAT EXCH IN  |                  | 617.3          | 4.46         | 2111.6            | 0.54         |
| GOX HEAT EXCH OUT |                  | 617.1          | 4.46         | 2111.6            | 0.54         |
| FSOV INLET        | 1889.1           | 617.4          | 4.46         | 2111.6            | 0.53         |
| FSOV EXIT         | 1841.8<br>1823.3 | 617.5          | 4.46         | 2111.6            | 0.52         |
| CHAMBER INJ       | 1696.5           | 027.12         |              |                   |              |
| CHAMBER           | 1070.5           |                |              |                   |              |
|                   |                  |                |              |                   |              |
|                   | # OXYO           |                | CONDITION    | S =               | DENSITY      |
| STATION           | PRESS            | TEMP           | FLON         | ENTHALPY          | 71.17        |
| B.P. INLET        | 16.0             | 162.7          | 26.8         | 61.3              | 71.20        |
| B.P. EXIT         | 135.6            | 163.2          | 26.8         | 61.5              | 71.20        |
| PUMP INLET        | 135.6            | 163.2          | 26.8         | 61.5<br>70.7      | 71.63        |
| PUMP EXIT         | 2747.5           | 175.9          | 26.8         | 204.7             | 0.12         |
| OZ TANK PRESS     |                  | 400.0          |              | 70.7              | 71.59        |
| OCV INLET         | 2720.0           | 176.0          | 26.8         | 70.7              | 70.32        |
| OCV EXIT          | 1904.0           | 179.1          | 26.8         | 70.7              | 70.26        |
| CHAMBER INJ       | 1866.1           | 179.3          | 26.8         | , , , , ,         |              |
| CHAMBER           | 1696.5           |                |              |                   |              |
|                   |                  |                |              |                   |              |
|                   |                  | WALVE D        | ATA =        |                   |              |
| VALVE             | DELTA P          |                | FLOH         | \$ BYPASS         |              |
| TBV               | 2674.            | 0.01           | 0.22         | 5.00              |              |
| FSOV              | 47.              | 1.30           | 4.46         |                   |              |
| OCV               | 816.             | 0.17           | 26.78        |                   |              |
| <b>T</b>          |                  |                |              |                   |              |
|                   |                  |                |              |                   |              |
|                   |                  | INJECTOR       |              | UEL DOTTY         |              |
| INJECTOR          | DELTA P          |                | FLON         | VELOCITY          |              |
| FUEL              | 127.             | 0.90           | 4.46         | 1388.26<br>149.56 |              |
| LOX               | 188.             | 0.37           | 26.78        | 147.30            |              |
|                   |                  |                |              |                   |              |

TABLE 10. — FULL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| * TURBOHACHI  | NERY PERFORMANCE DATA .                                  |
|---|--|
|   | ************   |
| *************   |  |
| . HZ BOOST TURBINE .  | * H2 BOOST PUMP =  |
| *************   | * 12 50031 FOF 8   |
| EFFICIENCY (T/T) 0.746  | EFFICIENCY 0.766   |
| EFFICIENCY (T/S) 0.391  | HORSEPONEN 29,   |
| SPEED (RPM) 53300.  | SPEED (RPM) 53300.                                       |
| MEAN DIA (IH) 1,16<br>EFF AREA (IH2) 1,80   | \$ SPEED 3048.   |
| 2. 44.  | HEAD (FT) 2693.<br>DIA. (IN) 1.89                        |
| U/C (ACTUAL) 0.550 MAX TIP SPEED 390.   |  |
| STAGES 1  | TIP SPEED 439.   |
| GAPPA 1.45  | VOL. FLOM 457.<br>HEAD COEF 9.450                        |
| PRESS RATIO (T/T) 1.01  | FLOW COEF 9.201  |
| PRESS RATIO (T/S) 1.02  | V.111  |
| HORSEPONER 29.  |  |
| EXIT MACH HUMBER 0.10<br>SPECIFIC SPEED 148.19  |  |
|   |  |
| SPECIFIC DIAMETER 0.52  |  |
|   |  |
| 202224472000E   |  |
| * H2 TURBINE *  | * H2 PUMP =  |
| **********  | * 72 700 0   |
|   | STAGE ONE STAGE THO STAGE THREE                          |
|   | HASSIBORE WEDDONESS DESCRIPTION                          |
| EFFICIENCY (T/T) 8.798  | EFFICIENCY 0.649 0.651 0.453                             |
| EFFICIENCY (T/S) 0.774  | HORSEPOHER 717. 781. 685.                                |
| SPEED (RPM) 136363.   | SPEED (RPH) 136363. 136363. 136363.                      |
|   | 33 G CLS 7387.   |
| MEAN DIA. (IN) 2.33<br>EFF AREA (IN2) 0.19<br>U/C (ACTUAL) 0.469<br>MAX TIP SPEED 1481. | S SPEED 789, 797, 885,<br>HEAD (FT) 57278, 56200, 55023. |
| INC (ACTUAL) 0.19   | HEAD (FT) 57278. 56200. 55023.                           |
| MAX TIP SPEED 1481  | DIA. (IN) 3.12 3.12 3.12<br>TIP SPEED 1859, 1859, 1859,  |
| STAGES 2  |  |
| GAPM 1.45   | HEAD COSE A COS A COS                                    |
| PRESS RATIO (T/T) 2.85  | FLON COEF 0.096  |
| PRESS RATIO (T/S) 2.08  | DIAMETER RATIO 9.331                                     |
| EXIT MACH HUMBER 0.15   | BEARING DN 3.00E+06                                      |
| SPECIFIC SPEED 39.56  | SHAFT DIAMETER 22.00                                     |
| SPECIFIC DIAMETER 1.66  |  |
|   |  |
| ****************  |  |
| . OZ BOOST TURBINE .  | * OZ BOOST PLPP *  |
| **************  | • 02 BOOS   POP •  |
|   |  |
| EFFICIENCY (T/T) 8.826  | EFFICIENCY 0.764   |
| EFFICIENCY (T/S) 0.607  | EFFICIENCY 0.764 HORSEPONER 15.                          |
| SPEED (RPH) 14272.  | SPEED (RPH) 14272.                                       |
| MEAN DIA (IN) 3.18<br>EFF AMEA (IN2) 2.64   | \$ SPEED 3024.   |
|   | HEAD (FT) 242.<br>DIA. (IN) 2.11                         |
| MAX TIP SPEED 235.  |  |
| STAGES 1  | TIP SPEED 132.<br>VOL. FLOM 169.                         |
| GAPA 1.45   | HEAD COEF 0.450  |
|   | FLON COEF 8.200  |
| PRESS RATIO (T/S) 1.01  | *****  |
| HORSEPONER 15.  |  |
| EXIT MACH HUMBER 0.03<br>SPECIFIC SPEED 96.92   |  |
|   |  |
| SPECIFIC DIMETER 0.86   |  |
|   |  |
| **********  | ********   |
| . 02 TURBINE .  | * 02 PUMP *  |
| **********  |  |
|   |  |
| EFFICIENCY (T/T) 0.817  | EFFICIENCY 0.730   |
| EFFICIENCY (T/S) 8,771  | HORSEPONER 351.  |
| SPEED (RPH) 87749.  | SPEED (RPH) 87749.                                       |
| HORSEPONER 351.   | SS SPEED 22303.  |
| MEAN DIA (IN) 2.33  | S SPEED 1845.  |
| EFF AREA (IN2) 0.29   | HEAD (FT) 5249.<br>DIA. (IN) 1.66                        |
| U/C (ACTUAL) 0.523<br>MAX TIP SPEED 952.  |  |
| MAX TIP SPEED 952.<br>STAGES 1  | TIP SPEED 634.   |
| GAPPA 1.45  | VOL. FLON 148.<br>HEAD COEF 8.428                        |
| PRESS RATIO (T/T) 1.11  | FLON COEF 0.155  |
| PRESS RATIO (T/S) 1.12  | DIAMETER RATIO 0.602                                     |
| EXIT HACH HUNGER 0.08   | BEARING DN 1.40E+94                                      |
| SPECIFIC SPEED 45.33  | SHAFT DIAMETER 16.08                                     |
| SPECIFIC DIAMETER 1.65  |  |
|   |  |

## TABLE 11. — FULL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER)

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1603.4 |
|------------------------|--------|
| VAC ENGINE THRUST      | 25000. |
| TOTAL ENGINE FLON RATE | 52.08  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 7.62   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 98.52  |
| ENGINE HIXTURE RATIO   | 6.00   |
| ETA C.                 | 0.993  |
| CHAMBER COOLANT DP     | 495.   |
| CHAMBER COOLANT DT     | 505.   |
| NOZZLE/CHAMBER Q       | 14356. |

|                                   | . FIFE           | SYSTEM CON     | DITIONS #    |                  |              |
|-----------------------------------|------------------|----------------|--------------|------------------|--------------|
| STATION                           | PRESS            | TEMP           | FLON         | ENTHALPY         | DENSITY      |
| B.P. INLET                        | 18.6             | 37.4           | 7.45         | -107.5           | 4.37         |
| B.P. EXIT                         | 100.9            | 38.5           | 7.45         | -103.0           | 4.39         |
| PUMP INLET                        | 100.9            | 38.5           | 7.45         | -103.0           | 4.39         |
| IST STAGE EXIT                    | 1458.6           | 54.9           | 7.45         | -25.5            | 4.50         |
| 2ND STAGE EXIT                    | 2831.9           | 70.7           | 7.45         | 51.8             | 4.58         |
| PUMP EXIT                         | 4222.8           | 84.2           | 7.45         | 128.6            | 4.67         |
| COOLANT INLET                     | 4180.6           | 86.6           | 7.45         | 128.6            | 4.65<br>1.02 |
| COOLANT EXIT                      | 3685.4           | 591.9          | 7.45         | 2055.1           | 1.01         |
| TBV INLET                         | 3648.5           | 592.1          | 0.37         | 2055.1<br>2055.1 | 0.53         |
| TBV EXIT                          | 1795.5           | 601.9          | 0.37         | 2055.1           | 1.01         |
| 02 TRB IMLET                      | 3648.5           | 592.1          | 7.08         | 2001.5           | 0.94         |
| 02 TRB EXIT                       | 3266.7           | 579.5          | 7.08<br>7.08 | 2001.5           | 0.94         |
| HZ TRB INLET                      | 3266.7           | 579.5          | 7.08         | 1757.7           | 0.64         |
| HE TRB EXIT                       | 1925.6           | 519.5<br>519.6 | 7.08         | 1757.7           | 0.63         |
| HZ TRB DIFFUSER                   | 1888.2           | 517.6          | 7.08         | 1757.7           | 0.63         |
| HZ BST TRB IN                     | 1869.3           | 518.5          | 7.08         | 1753.0           | 0.62         |
| H2 BST TRB OUT                    | 1848.2<br>1834.8 | 518.6          | 7.08         | 1753.0           | 0.62         |
| HZ BST TRB DIFF                   |                  | 518.6          | 7.08         | 1753.0           | 0.61         |
| 02 BST TRB IN                     | 1816.4<br>1806.0 | 518.0          | 7.08         | 1750.4           | 0.61         |
| 02 BST TRB OUT<br>02 BST TRB DIFF | 1804.5           | 518.0          | 7.08         | 1750.4           | 0.61         |
| 02 BST TRB DIFF                   | 18.6             | 529.4          | 0.0113       | 1765.6           | 0.0066       |
| GOX HEAT EXCH IN                  |                  | 522.2          | 7.44         | 1765.6           | 0.60         |
| GOX HEAT EXCH OUT                 |                  | 521.9          | 7.44         | 1764.3           | 0.60         |
| FSOV INLET                        | 1786.5           | 521.9          | 7.44         | 1764.3           | 0.60         |
| FSOV EXIT                         | 1741.9           | 522.1          | 7.44         | 1764.3           | 0.58         |
| CHAMBER INJ                       | 1724.3           | 522.2          | 7.44         | 1764.3           | 0.58         |
| CHAMBER                           | 1603.6           |                |              |                  |              |
| <b>G</b> 12 12 12 1               |                  |                |              |                  |              |
|                                   | - ~~             | YGEN SYSTEM    | COMBITION    | s •              |              |
|                                   |                  | TEMP           | FLON         | ENTHALPY         | DENSITY      |
| STATION                           | PRESS<br>16.0    | 162.7          | 44.7         | 61.1             | 71.17        |
| B.P. INLET                        |                  | 163.2          | 44.7         | 61.5             | 71.28        |
| B.P. EXIT                         | 135.6<br>135.6   | 163.2          | 44.7         | 61.5             | 71.20        |
| PUMP INLET                        | 2596.8           | 174.6          | 44.7         | 70.0             | 71.69        |
| PUMP EXIT                         | 16.0             | 400.0          | 0.076        | 204.7            | 0.12         |
| 02 TANK PRESS                     | 2570.9           | 174.7          | 44.6         | 70.0             | 71.65        |
| OCV INLET                         | 1799.6           | 177.6          | 44.6         | 70.0             | 70.45        |
| CHAMBER INJ                       | 1763.8           | 177.8          | 44.6         | 70.0             | 70.39        |
| CHAMBER                           | 1603.4           |                |              |                  |              |
| CHARDON                           |                  |                |              |                  |              |
|                                   |                  |                |              |                  |              |
|                                   |                  | - VALVE D      |              | * BYPASS         |              |
| VALVE                             | DELTA P          |                | FLOH<br>0.37 | 5.00             |              |
| TBV                               | 1853.            |                | 7.44         | 3.00             |              |
| FSOV                              | 45.              |                | 44.64        |                  |              |
| OCA                               | 771.             | 0.28           | 77.07        |                  |              |
|                                   |                  |                |              |                  |              |
|                                   |                  | # INJECTOR     | DATA =       |                  |              |
| INJECTOR                          | DELTA F          |                | FLOH         | VELOC1TY         |              |
| FUEL                              | 121              |                | 7.44         | 1291.05          |              |
| LOX                               | 178              | 0.63           | 44.64        | 145.27           |              |
|                                   |                  |                |              |                  |              |

TABLE 11. — FULL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| •   | TURBONACHI    | INERY PERFORMANCE  | DATA .         |                        |               |
|---|---------------|--|----------------|------------------------|---------------|
| • H2 BOOST TI   | ******        | •  | H2 BOOST P     |                        |               |
| *********   |               |  | ********       |                        |               |
| EFFICIENCY (T/T)  | 0.823         | EFF 1  | CIENCY         | 0.765                  |               |
| EFFICIENCY (T/S)  |               | HORS   | 20ER           | 48.                    |               |
| SPEED (RPH)<br>HEAN DIA (IN)  | 1.44          | SPEE   | D (RPH)<br>EED | 41350.                 |               |
| EFF AREA (IN2)  | 2.82          | HEAD   | (FT)           | 3045.<br>2703.         |               |
| U/C (ACTUAL) MAX TIP SPEED  | 0.538         | DIA.   | (FT)<br>(IN)   | 2.43                   |               |
|   |               | TIP  | SPEED<br>FLOW  | 440.<br>762.           |               |
| GAMMA PRESS RATIO (T/T) PRESS RATIO (T/S)   | 1.34          | HEAD   | COEF           | 0.450                  |               |
| PRESS RATIO (T/T)   | 1.01          | FLON   | COEF           | 0.450<br>0.201         |               |
| HORSEPONER  | 48.           |  |                |                        |               |
| EXIT MACH MUMBER  | 0.11          |  |                |                        |               |
| SPECIFIC SPEED<br>SPECIFIC DIAMETER   |               |  |                |                        |               |
|   |               |  |                |                        |               |
| *********   |               |  | *********      |                        |               |
| . HZ TURBINE  |               |  | . HZ PUMP      | •                      |               |
| **********  | •             |  | 2141411111     |                        |               |
|   |               |  |                |                        | STAGE THREE   |
| EFFICIENCY (T/T) EFFICIENCY (T/S) SPEED (RPH) HORSEPOMER HEAN DIA. (IN) EFF AREA (IN2) U/C (ACTUAL) HAX TIP SPEED | 0.063         | EFF1C1ENCY   | 0.726          | 0.725                  | 8.724         |
| SPEED (RPH)   | 125000.       | MORSEPONER   | 817.           | 813.                   | 810.          |
| HORSEPONER  | 2441.         | SS SPEED   | 11310.         | 125000.                | 125000.       |
| HEAN DIA. (IN)  | 2.36          | S SPEED  | 1126.          | 1121.                  | 1115.         |
| U/C (ACTUAL)  | 0.33          | HEAD (FT)  | 43769.         | 43508.                 | 43284.        |
| HAX TIP SPEED   |               | TIP SPEED  | 1671.          | 1670.                  | 3.06<br>1671. |
|   | 2             | VOL. FLON  | /43.           | 730.                   | 717.          |
| GAMMA PRESS RATIO (T/T) PRESS RATIO (T/S) EXIT MACH NUMBER  | 1.34          | HEAD COEF<br>FI OM COEF  | 8.504<br>0.118 | 0.502                  | 8.499         |
| PRESS RATIO (T/S)   | 1.74          | DIAMETER RATIO   | 0.412          |                        |               |
| EXIT MACH MUMBER<br>SPECIFIC SPEED  | 0.18          | HEAD COEF<br>FLOW COEF<br>DIAMETER RATIO<br>BEARING ON<br>SHAFT DIAMETER | 3.00E+06       |                        |               |
| SPECIFIC DIMETER  | 1.26          | SHAFT DIMMETER   | 24.00          |                        |               |
| *********   |               |  |                |                        |               |
| # 02 BOOST TUR  |               |  | 02 BOOST PU    |                        |               |
| **********  | ******        |  | **********     |                        |               |
| EFFICIENCY (T/T)  |               | EFF 1C   | IDICY          | 0.764                  |               |
| EFFICIENCY (T/S)  |               | HORSE  | POMER          | 26.                    |               |
| SPEED (RPH)<br>MEAN DIA (IN)  | 4.11          | 3/220  | (RPH)          | 26.<br>11055.<br>3026. |               |
| EFF AREA (IN2)  | 4.06          | HEAD   | (FT)           | 242.                   |               |
| U/C (ACTUAL)  |               | DIA.   | (FT)<br>(IN)   | 2.72                   |               |
| MAX TIP SPEED<br>STAGES   | 233.<br>1     | TIP SP<br>VOL. F   | TEU .          | 132.<br>282.           |               |
| GAHNA   | 1.34          | MEAN A   | ~~~            | 0.450                  |               |
| GAMMA PRESS RATIO (T/T) PRESS RATIO (T/S)   | 1.01          | FLOM (   | X0EF           | 0.200                  |               |
| HORSEPOHER  | 26.           |  |                |                        |               |
| EXIT MACH HUMBER<br>SPECIFIC SPEED  | 0.04          |  |                |                        |               |
| SPECIFIC DIAMETER   |               |  |                |                        |               |
|   |               |  | ٠,             |                        |               |
| *********   |               |  |                |                        |               |
| * 02 TURBINE *  |               |  | 02 PUMP #      |                        |               |
| ***************************************   |               | •  | ********       |                        |               |
| EFFICIENCY (T/T)  |               | EFF ICI  |                | 0.747                  |               |
| EFFICIENCY (T/S) SPEED (RPH)  |               | HORSEP   | (004)          | 538.<br>65861.         |               |
| HORSEPOHER  | 538.          | 22 256   |                | 21611.                 |               |
| MEAN DIA (IN)<br>EFF AREA (IN2)   | 2.36          |  |                | 1870.                  |               |
| U/C (ACTUAL)  | 0.54<br>0.414 | HEAD<br>BIA  | (FT)<br>(IN)   | 4942.<br>2.12          |               |
| MAX TIP SPEED   | 746.          | TIP SPI  | EED            | 611.                   |               |
| STAGES<br>GAPPIA  | 1             | VOL. FI  |                | 280.                   |               |
| PRESS RATIO (T/T)   | 1.34          | HEAD CI<br>FLOH CI   |                | 0.426<br>0.156         |               |
| PRESS RATIO (T/S)   | 1.13          |  | ER RATIO       | 0.156                  |               |
| EXIT MACH NUMBER<br>SPECIFIC SPEED  | 0.12          | BEARING  | 3 DN 1.        | 45E+06                 |               |
| SPECIFIC SPEED  | 47.79<br>1.27 | SHAFT I  | LAMETER        | 22.00                  |               |
|   |               |  |                |                        |               |

## TABLE 12. — FULL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER)

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1502.9 |
|------------------------|--------|
| VAC ENGINE THRUST      | 37500. |
| TOTAL ENGINE FLOH RATE | 78.13  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 12.19  |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 124.61 |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C#                 | 0.993  |
| CHAMBER COOLANT DP     | 447.   |
| CHAMBER COOLANT DT     | 420.   |
| NOZZLE/CHAMBER Q       | 18018. |

| •                 |                  |                |                |                  |                |  |
|-------------------|------------------|----------------|----------------|------------------|----------------|--|
|                   | * FUEL           | SYSTEM CON     | DITIONS #      |                  |                |  |
| HOITATZ           | PRESS            | TEMP           | FLOM           | ENTHALPY         | DENSITY        |  |
| B.P. INLET        | 18.6             | 37.4           | 11.18          | -107.5           | 4.37           |  |
| B.P. EXIT         | 100.3            | 38.5           | 11.18          | -103.0           | 4.39           |  |
| PUMP INLET        | 100.3            | 38.5           | 11.18          | -103.0           | 4.39           |  |
| IST STAGE EXIT    | 1523.0           | . 55.0         | 11.18          | -23.6            | 4.52           |  |
| 2ND STAGE EXIT    | 2971.B           | 70.9           | 11.18          | 55.8             | 4.63           |  |
| PUMP EXIT         | 4445.4           | 86.4           | 11.18          | 135.0            | 4.72           |  |
| COOLANT INLET     | 4400.9           | 86.8           | 11.18          | 135.0            | 4.70           |  |
| COOLANT EXIT      | 3953.5           | 507.0          | 11.18          | 1746.4           | 1.25           |  |
| TBV INLET         | 3914.0           | 507.2          | 8.54           | 1746.4           | 1.24           |  |
| TBV EXIT          | 1682.1           | 517.4          | 0.56           | 1746.4           | 1.24           |  |
| 02 TRB INLET      | 3914.0           | 507.2          | 10.62          | 1746.4           | 1.14           |  |
| O2 TRB EXIT       | 3491.1           | 495.9          | 10.62          | 1697.1<br>1697.1 | 1.14           |  |
| H2 TRB INLET      | 3491.1           | 495.9          | 10.62          | 1446.6           | 0.72           |  |
| H2 TRB EXIT       | 1818.3           | 435.6          | 10.62          | 1446.6           | 0.71           |  |
| H2 TRB DIFFUSER   | 1774.3           | 435.7          | 10.62          | 1446.6           | 0.71           |  |
| H2 BST TRB IN     | 1756.6           | 435.7          | 10.62          | 1441.9           | 0.69           |  |
| HZ BST TRB OUT    | 1733.8           | 434.6          | 10.62          | 1441.9           | 0.69           |  |
| H2 BST TRB DIFF   | 1720.7           | 434.6          | 10.62<br>10.62 | 1441.9           | 0.68           |  |
| 02 BST TRB IN     | 1703.5           | 434.7          | 10.62          | 1439.3           | 0.68           |  |
| OZ BST TRB OUT    | 1692.0           | 434.0          | 10.62          | 1439.3           | 0.68           |  |
| 02 BST TRB DIFF   | 1690.5           | 434.0<br>442.8 | 0.0203         | 1454.7           | 0.0079         |  |
| H2 TANK PRESS     | 18.6             | 438.2          | 11.16          | 1454.7           | 0.67           |  |
| GOX HEAT EXCH IN  | 1682.1           | 438.2          | 11.16          | 1453.3           | 0.67           |  |
| GOX HEAT EXCH OUT |                  | 437.8          | 11.16          | 1453.3           | 0.67           |  |
| FSOV INLET        | 1673.7<br>1631.8 | 438.0          | 11.16          | 1453.3           | 0.65           |  |
| FSOV EXIT         | 1615.5           | 438.0          | 11.16          | 1453.3           | 0.64           |  |
| CHAMBER INJ       | 1502.9           | 430.0          |                |                  |                |  |
| CHAMBER           | 1502.7           |                |                |                  |                |  |
|                   |                  |                |                |                  |                |  |
|                   | ■ OXY            |                | CONDITION      | S •              | ne             |  |
| MOITATE           | PRESS            | TEMP           | FLOH           | ENTHALPY         | DENSITY        |  |
| B.P. INLET        | 16.0             | 162.7          | 67.1           | 61.1             | 71.17<br>71.20 |  |
| B.P. EXIT         | 135.6            | 163.2          | 67.1           | 61.5             | 71.20          |  |
| PUMP INLET        | 135.4            | 163.2          | 67.1           | 61.5             | 71.71          |  |
| PUMP EXIT         | 2433.9           | 173.5          | 67.1           | 69.3             | 0.12           |  |
| 02 TANK PRESS     | 16.0             | 400.0          | 0.113          | 204.7<br>69.3    | 71.67          |  |
| OCV INLET         | 2409.6           | 173.6          | 67.0           | 69.3             | 70.55          |  |
| OCV EXIT          | 1686.7           | 176.4          | 67.0           | 69.3             | 70.50          |  |
| CHAMBER INJ       | 1653.1           | 176.5          | 67.0           | 67.3             |                |  |
| CHAMBER           | 1502.9           |                |                |                  |                |  |
|                   |                  |                |                |                  |                |  |
|                   |                  | . VALVE D      | ATA P          |                  |                |  |
| VALVE             | DELTA P          | AREA           | FLON           | * BYPASS         |                |  |
| TBV               | 2232.            | 0.02           | 0.54           | 5.00             |                |  |
| FSOV              | 42.              | 3.09           | 11.16          |                  |                |  |
|                   | 723.             | 0.44           | 66.97          |                  |                |  |
| DCV               |                  | • • • •        |                |                  |                |  |
|                   |                  |                |                |                  |                |  |
|                   |                  | INJECTOR       |                |                  |                |  |
| INJECTOR          | DELTA P          |                | FLON           | VELOCITY         |                |  |
| FUEL              | 113.             | 2.13           | 11.16          | 1181.21          |                |  |
| LOX               | 167.             | 0.97           | 66.97          | 140.53           |                |  |
|                   |                  |                |                |                  |                |  |

TABLE 12. — FULL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

#### \* TURBOMACHINERY PERFORMANCE DATA \* ------# H2 BOOST TURBINE # \*\*\*\*\*\*\*\*\*\*\* EFFICIENCY (T/T) 0.848 EFFICIENCY (T/S) 0.479 EFF ICIPACY 9.766 HORSEPOHER 71. SPEED (RPM) 33637. HEAN DIA (IN) 1.78 EFF AREA (IN2) 3.85 SPEED (RPH) S SPEED 33637. 3051. HEAD (FT) DIA. (IH) TIP SPEED 2481. U/C (ACTUAL) MAX TIP SPEED 370. 438. STAGES VOL. FLON HEAD COEF GAMMA 1.42 0.450 PRESS RATIO (T/T) 1.01 FLOH COOF PRESS RATIO (T/S) 0.201 1.02 71. EXIT MACH NUMBER SPECIFIC SPEED 150.00 SPECIFIC DIAMETER 0.54 \*\*\*\*\*\*\*\*\*\* \*\*\*\*\*\*\*\*\* . H2 TURBINE . . H2 PUMP . \*\*\*\*\*\*\*\*\* STAGE DNE STAGE THO STAGE THREE EFFICIENCY (T/T) 0.865 EFFICIENCY (T/S) 0.827 SPEED (RPH) 107)43. HORSEPOMER 1764. MEAN DIA. (1M) 2.61 EFF AREA (1M2) 0.488 U/C (ACTUAL) 0.488 ...... ...... ....... **EFFICIENCY** 0.730 0.737 HORSEPONER 1256. SPEED (RPM) 107143. 107143. 107143. \$\$ \$PEED 11947. S SPEED 1142. 1132. 1124 HEAD (FT) DIA. (IN) TIP SPEED 45690. 3.64 45553. 45391. 3.64 1702. 3.64 MAX TIP SPEED STAGES 1347. 1702. 1702. VOL. FLOH 1110. 1005. 1.42 PRESS RATIO (T/T) PRESS RATIO (T/S) HEAD COEF 0.507 0.504 1.92 FLON COEF 0.119 1.78 DIANETER RATIO EXIT MACH HUMBER SHAFT DIAMETER 90 ---0.20 SPECIFIC DIMETER 1.21 P 02 BOOST TURBINE H # 02 BOOST PUMP . EFFICIENCY (T/T) EFFICIENCY (T/S) 0.887 0.764 0.754 HORSEPONER SPEED SPEED (RPH) HEAN DIA (IN) EFF AREA (IN2) SPEED (RPH) S SPEED HEAD (FT) DIA, (IN) 9024. 9024 5.03 5.48 242. U/C CACTUA MAX TIP SPEED (ACTUAL) 0.553 DIA, (IN) TIP SPEED 3.34 231. 132. VOL. FLON HEAD COEF STAGES GAPPIA 8.450 PRESS RATIO (T/T) PRESS RATIO (T/S) 1.01 FLOH COFF 8.200 1.01 39. EXIT MACH MINNER SPECIFIC SPEED 93.06 SPECIFIC DIAMETER .......... # 02 TURBINE # - 02 PUMP + EFFICIENCY (T/T) 8.877 **EFFICIENCY** 0.760 EFFICIENCY (T/S) 0.826 HORSEPOMER SPEED (RPH) 52014. SPEED (RPM) 52814. HORSEPONER SS SPEED S SPEED HEAD (FT) 740. 20904. MEAN DIA (IN) EFF AREA (IN2) 2.61 1904 0.68 4613. (ACTUAL) U/C DIA. (IN) 2.58 MAX TIP SPEED 667. TIP SPEED 587. STAGES VOL. FLON HEAD COEF 420. GAMMA 1.62 0.431 PRESS RATIO (T/T) 1.12 FLON COEF 8.158 PRESS RATIO (T/S) 1.13 DIAMETER RATIO 0.484 EXIT MACH NUMBER BEARING DN 1.46E+06 SHAFT DIAMETER 28.00 0.09 SPECIFIC SPEED SPECIFIC DIAMETER

## TABLE 13. — FULL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER TUBE CHAMBER)

#### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1402.6 |
|------------------------|--------|
| VAC ENGINE THRUST      | 50000. |
| TOTAL ENGINE FLOW RATE | 104.18 |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 17.41  |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 148.90 |
| ENGINE MIXTURE RATIO   | 6.00   |
| FTA C*                 | 0.993  |
| CHAMBER COOLANT DP     | 355.   |
| CHAMBER COOLANT DT     | 383.   |
| NOZZLE/CHAMBER Q       | 21899. |

|                                |                  | YSTEM CON    | FLON       | ENTHALPY | DENSITY |
|--------------------------------|------------------|--------------|------------|----------|---------|
| STATION                        | PRESS            | TEMP         | 14.91      | -107.5   | 4.37    |
| B.P. INLET                     | 18.6             | 37.4<br>38.5 | 14.91      | -103.0   | 4.39    |
| B.P. EXIT                      | 100.2            | 38.5         | 14.91      | -103.0   | 4.39    |
| PUMP INLET                     | 100.2            | 51.6         | 14.91      | -37.9    | 4.53    |
| IST STAGE EXIT                 | 1308.4           | 64.4         | 14.91      | 27.5     | 4.65    |
| 2ND STAGE EXIT                 | 2547.4           | 76.7         | 14.91      | 93.1     | 4.73    |
| PUMP EXIT                      | 3813.5           | 77.1         | 14.91      | 93.1     | 4.71    |
| COOLANT INLET                  | 3775.4<br>3420.6 | 459.9        | 14.91      | 1561.6   | 1.20    |
| COOLANT EXIT                   | 3386.4           | 460.0        | 0.75       | 1561.6   | 1.19    |
| TBV INLET                      | 1570.3           | 467.3        | 0.75       | 1561.6   | 0.59    |
| TBV EXIT                       | 3386.4           | 460.0        | 14.17      | 1561.6   | 1.19    |
| OZ TRB INLET                   | 3016.7           | 449.7        | 14.17      | 1516.4   | 1.10    |
| OZ TRB EXIT                    | 3016.7           | 449.7        | 14.17      | 1516.4   | 1.10    |
| H2 TRB INLET                   | 1706.6           | 400.3        | 14.17      | 1309.9   | 0.74    |
| H2 TRB EXIT<br>H2 TRB DIFFUSER | 1659.7           | 400.4        | 14.17      | 1309.9   | 0.72    |
| H2 BST TRB IN                  | 1643.1           | 400.4        | 14.17      | 1309.9   | 0.72    |
| H2 BST TRB OUT                 | 1620.3           | 399.3        | 14.17      | 1305.2   | 0.71    |
| H2 BST TRB DIFF                | 1607.4           | 399.3        | 14.17      | 1305.2   | 0.70    |
| 02 BST TRB IN                  | 1591.3           | 399.4        | 14.17      | 1305.2   | 0.70    |
| OZ BST TRB OUT                 | 1579.8           | 398.7        | 14.17      | 1302.6   | 0.69    |
| OZ BST TRB DIFF                | 1578.2           | 398.7        | 14.17      | 1302.6   | 0.69    |
| H2 TANK PRESS                  | 18.6             | 405.3        | 0.0296     | 1315.5   | 0.0087  |
| GOX HEAT EXCH IN               | 1570.3           | 402.1        | 14.88      | 1315.5   | 0.68    |
| GOX HEAT EXCH OUT              | 1562.5           | 401.8        | 14.88      | 1314.2   | 0.68    |
| FSOV INLET                     | 1562.5           | 401.8        | 14.88      | 1314.2   | 0.68    |
| FSOV EXIT                      | 1523.4           | 401.9        | 14.88      | 1314.2   | 0.66    |
| CHAMBER INJ                    | 1508.2           | 401.9        | 14.88      | 1314.2   | 0.66    |
| CHAMBER                        | 1402.6           |              |            |          |         |
|                                | - 044            | THE CVETEM   | CONDITIONS | s •      |         |
|                                | PRESS            | TEMP         | FLOH       | ENTHALPY | DENSITY |
| STATION                        | 16.0             | 162.7        | 89.4       | 61.1     | 71.17   |
| B.P. INLET                     | 135.6            | 163.2        | 89.4       | 61.5     | 71.20   |
| B.P. EXIT                      | 135.6            | 163.2        | 89.4       | 61.5     | 71.20   |
| PUMP INLET                     | 2271.6           | 172.6        | 89.4       | 68.6     | 71.71   |
| PUMP EXIT 02 TANK PRESS        | 16.0             | 400.0        | 0.151      | 204.7    | 0.12    |
| OCV INLET                      | 2248.8           | 172.7        | 89.3       | 68.6     | 71.67   |
| DCV EXIT                       | 1574.2           | 175.3        | 89.3       | 68.6     | 70.62   |
| CHAMBER INJ                    | 1558.4           | 175.3        | 89.3       | 68.6     | 70.60   |
| CHAMBER                        | 1402.6           | -            |            |          |         |
|                                |                  |              | •• -       |          |         |
|                                |                  | • VALVE DA   | NIA -      |          |         |
| VALVE                          | DELTA P          | AREA         | FLON       | % BYPASS |         |
| TBV                            | 1816.            | 0.03         | 0.75       | 5.00     |         |
| FSOV                           | 39.              | 4.22         | 14.88      |          |         |
| ocv                            | 675.             | 0.61         | 89.29      |          |         |
|                                |                  | INJECTOR     | DATA =     |          |         |
|                                |                  | ARE <b>A</b> | FLON       | VELOCITY |         |
| INJECTOR                       | DELTA P          | 2.68         | 14.88      | 1131.21  |         |
| FUEL                           | 106.             | 1.27         | 89.29      | 135.69   |         |
| LOX                            | 156.             | 1.27         | 07.47      |          |         |

TABLE 13. — FULL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| ********   | 化二甲基甲基甲基甲基甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲甲 |  |
|--|---|--|
| # TURBOHACH  | INERY PERFORMANCE DATA *                |  |
| *******  |   |  |
| #####################################  | *********                               |  |
|  | # H2 BOOST F                            |  |
| EFFICIENCY (T/T) 0.861   | EFFICIENCY                              |  |
| EFFICIENCY (T/S) 0.489   | HORSEPOHER                              | 0.766<br>95.   |
| SPEED (RPM) 29123.   | SPEED (RPM)                             | 29123.   |
| MEAN DIA (IN) 2.04<br>EFF AREA (IN2) 5.09  | S SPEED                                 | 3051   |
| U/C (ACTUAL) 0.533   | HEAD (FT)<br>DIA. (IN)                  | 2682.  |
| MAX TIP SPEED 367.   | DIA. (IN)                               |  |
| STAGES 1   | TIP SPEED<br>VOL. FLOW                  | 438.   |
| GAMMA 1.41   | HEAD COEF                               | 1525.<br>0.450   |
| PRESS RATIO (T/T) 1.01   | FLOH COEF                               | 0.201  |
| PRESS RATIO (T/S) 1.02 HORSEPOWER **   |   |  |
| HORSEPOHER 95. EXIT MACH NUMBER 0.11   |   |  |
| SPECIFIC SPEED 150.00  |   |  |
| SPECIFIC DIAMETER 0.54   |   |  |
|  |   |  |
| " H2 TURBINE .   | ******                                  |  |
| and the property of the proper | # H2 PUMP                               |  |
|  | BRESSES STATE OME                       | STAGE THO STAGE THREE                                    |
|  | 2. 大                                    | STAGE THO STAGE THREE                                    |
| EFFICIENCY (T/T) 0.889   | EFFICIENCY 0.764                        | 0.763 0.763  |
| EFFICIENCY (T/S) 0.838<br>SPEED (RPM) 100000.  | HORSEPOHER 1375. SPEED (RPM) 100000.    | 1380. 1384.  |
| HORSEPOHER 4139.   | SPEED (RPM) 100000.<br>SS SPEED 12880.  | 100000. 100000.  |
| MEAN DIA. (IN) 2.83<br>EFF AREA (IN2) 0.71   | 33 3FEED 12880.                         |  |
| EFF AREA (IN2) 0.71  | 5 SPEED 1391.<br>HEAD (FT) 38744.       | 13/2. 1359.<br>38828 70075                               |
| U/C (ACTUAL) 0.544   | DIA. (IN) 3.68                          | 3.68 3.49  |
| U/C (ACTUAL) 0.544 MAX TIP SPEED 1383. STAGES 2  | TIP SPEED 1609.                         | 1372. 1359.<br>38828. 38875.<br>3.68 3.69<br>1609. 1609. |
| GAMMA 1.41   | VOL. FLOW 1476.                         | 4713.  |
| PRESS RATIO (T/T) 1.77   | HEAD COEF 0.481<br>FLOH COEF 0.133      | 0.483 0.483  |
| PRESS RATIO (T/S) 1.83   | DIAMETER RATIO 0.472                    |  |
| EXIT MACH NUMBER 0.21  | BEARING DN 3.00F+06                     |  |
| SPECIFIC SPEED 73.38 SPECIFIC DIAMETER 1.12  | SHAFT DIAHETER 30.00                    |  |
| a con to bracier 1.12  |   |  |
| 医  | 1 医复数皮肤 电电阻 医原体虫                        |  |
| # 02 BOOST TURBINE #   | # 02 BOOST PUR                          |  |
| EFFICIENCY (T/T) 0.896   | <b>网络安全的</b> 国际保持会会                     |  |
| EFFICIENCY (T/S) 0.762   | EFFICIENCY<br>HORSEPOHER                |  |
| SPEED (RPM) 7817   | SPEED (RPM)                             | 51.<br>7817.   |
| MEAN DIA (IN) 5.81<br>EFF AREA (IN2) 7.23  | S SPEED                                 | 3026.  |
| EFF AREA (IN2) 7.23  | HEAD (FT)<br>D1A. (IN)                  | 242.   |
| U/C (ACTUAL) 0.553<br>MAX TIP SPEED 230.   | DIA. (IN)                               | 3.85   |
| STAGES 1   | TIP SPEED<br>VOL. FLOW                  | 132.   |
| GAMMA 1.41   | HEAD COEF                               | 564.<br>0.450  |
| PRESS RATIO (T/T) 1.01   | FLOH COEF                               | 0.200  |
| PRESS RATIO (T/S) 1.01<br>HORSEPOMER 51.   |   |  |
| HORSEPOMER 51. EXIT MACH NUMBER 0.04   |   |  |
| EXIT MACH NUMBER 0.04 SPECIFIC SPEED 93.04   |   |  |
| SPECIFIC DIAMETER 0.92   |   |  |
| ****   |   |  |
| # OZ TURBINE #   | **************************************  |  |
| *********  | я О2 РИМР и<br>имининания               |  |
| EFFICIENCY (T/T) 0.879   |   | 0.769  |
| EFFICIENCY (T/S) 0.822<br>SPEED (RPH) 63561.   | EFFICIENCY<br>HORSEPOHER                | 907.   |
| HORSEPOHER 907.  | SPEED (RPM)                             | 43561.   |
| MEAN DIA (IN) 2.83   | SS SPEED<br>S SPEED                     | 20215.   |
| EFF AREA (IN2) 1.00  |   | 1945.<br>4287.   |
| U/C (ACTUAL) 0.506   | HEAD (FT)<br>DIA. (IN)                  | 2.96   |
| MAX TIP SPEED 617.<br>STAGES 2   | TIP SPEED                               | 564.   |
| GAMMA 1.41   | VOL. FLON                               | 560.   |
| PRESS RATIO (T/T) 1.12   |   | 0.434  |
| PRESS RATIO (T/S) 1.13   | FLOW COEF<br>DIAMETER RATIO             | 0.160  |
| FM   |   | 0.686  |
| EXIT MACH NUMBER 0.10  | BEARING DN 1.                           | 31E+06   |
| EXIT MACH NUMBER 0.10 SPECIFIC SPEED 77.88 SPECIFIC DIAMETER 0.99  | BEARING DN 1.:<br>SHAFT DIAMETER        | 31E+06<br>30.00  |

TABLE 14. — SPLIT-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER)

| CHAMBER PRESSURE       | 1329.9    |
|------------------------|-----------|
| VAC ENGINE THRUST      | 7500.     |
| TOTAL ENGINE FLOH RATE | 15.63     |
|                        | 479.9     |
| DEL. VAC. ISP          | 2.75      |
| THROAT AREA            | 1000.0    |
| NOZZLE AREA RATIO      | 59.21     |
| NOZZLE EXIT DIAMETER   | 6.00      |
| ENGINE MIXTURE RATIO   | • • • • • |
| ETA C#                 | 0.993     |
| CHAMBER COOLANT DP     | 1300.     |
| CHAMBER COOLANT DT     | 1071.     |
| MOZZI EZCHAMBER Q      | 4397.     |

| STATION PRESS TEMP FLOW ENTHALPY DENSITY B.P. IMLET 18.6 37.4 2.23 -107.5 4.37 B.P. EXIT 100.3 38.5 2.23 -103.0 4.39 PUMP IMLET 100.3 38.5 2.23 -103.0 4.39 PUMP IMLET 100.3 38.5 2.23 113.7 4.30 IST STAGE EXIT 1787.3 66.4 2.23 113.7 4.30 JBY IMLET 1760.5 66.6 1.12 113.9 4.28 JBY IMLET 160.5 66.6 1.12 13.9 4.09 PUMP EXIT 4981.0 137.3 1.12 298.4 3.98 PUMP EXIT 4981.0 137.3 1.12 298.4 3.98 COOLANT IMLET 6931.2 137.7 1.12 298.4 3.98 COOLANT IMLET 5631.6 1208.7 1.12 4234.7 0.53 TBY IMLET 3595.2 1209.0 0.06 4234.7 0.52 TBY EXIT 567.0 1223.8 0.06 4234.7 0.52 TBY EXIT 1567.0 1263.8 0.06 4234.7 0.52 D2 TRB IMLET 3240.7 1184.9 1.06 4140.6 0.48 THE TRB EXIT 1601.4 1040.3 1.06 3595.0 0.29 THE TRB DIFF 1641.7 1040.4 1.06 3595.0 0.29 THE TRB DIFF 1641.7 1040.4 1.06 3595.0 0.28 THE BY TRB DIFF 1641.7 1040.4 1.06 3595.0 0.28 THE BY TRB DIFF 1661.4 1038.0 1.06 3585.5 0.28 THE BY TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 THE BY TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 THE BY TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 THE ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 THE TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 THINER HOT IN 1559.1 1045.4 1.12 3610.3 0.27 THANBER HOT IN 1559.1 1045.4 1.12 3610.3 0.27 THANBER HOT IN 1481.2 535.9 2.23 1810.7 0.49 THANBER 1NJ 1429.7 536.2 2.23 1810.7 0.49  |                  | . 6151      | CVCTEM CON | DITIONS * |          |         |
|--|------------------|-------------|------------|-----------|----------|---------|
| STATION  B.P. IMLET  B.P. IMLET  B.P. EXIT  100.3  38.5  2.23  -103.0  4.39  B.P. EXIT  100.3  38.5  2.23  -103.0  4.39  B.P. EXIT  100.3  38.5  2.23  -103.0  4.39  IST STAGE EXIT  1787.3  66.4  2.23  13.7  4.30  IST STAGE EXIT  1787.3  66.6  1.12  113.9  4.09  JBV INLET  JBV INLET  JBV EXIT  1496.4  68.6  1.12  113.9  4.09  PUMP EXIT  COOLANT 1MLET  4981.0  1377.3  1.12  298.4  3.96  COOLANT EXIT  5631.6  1208.7  1.12  298.4  3.96  COOLANT EXIT  1567.0  1223.8  0.06  4234.7  0.53  TBV EXIT  1567.0  1223.8  0.06  4234.7  0.52  02 TRB EXIT  3240.7  1184.9  1.06  4140.6  0.48  M2 TRB INLET  3240.7  1184.9  1.06  4140.6  0.48  M2 TRB INLET  1557.5  1040.3  1.06  3595.0  0.29  M2 TRB EXIT  1661.7  1040.4  1.06  3595.0  0.29  M2 BST TRB IN  1657.5  1040.3  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M2 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M3 BST TRB DIFF  1601.4  1038.0  1.06  3585.5  0.28  M3 BST TRB DIFF  1574.8  1036.7  1.06  3580.4  0.27  0.28 BST TRB DIFF  1574.8  1036.7  1.06  3580.4  0.27  M1KER COLD IN  1559.1  1045.4  1.12  3610.3  0.27  MIKER COLD IN  1481.2  535.9  2.23  1810.7  0.49  FSOV EXIT  1442.7  536.2  2.23  1810.7  0.48  FSOV EXIT  1442.7  536.2  2.23  1810.7  0.47  |                  |             |            |           | ENTHALPY | DENSITY |
| B.P. EXIT 100.3 38.5 2.23 -103.0 4.39 PUMP INLET 100.3 38.5 2.23 -103.0 4.39 PUMP INLET 100.3 38.5 2.23 13.7 4.30 1ST STAGE EXIT 1787.3 66.4 2.23 13.7 4.30 JBV INLET 1760.5 66.6 1.12 13.9 4.28 JBV INLET 1696.4 68.6 1.12 13.9 4.28 PUMP EXIT 1696.4 68.6 1.12 164.0 4.05 PUMP EXIT 4981.0 137.3 1.12 298.4 3.98 PUMP EXIT 4981.0 137.7 1.12 298.4 3.98 PUMP EXIT 4531.6 1208.7 1.12 4234.7 0.52 TBV INLET 5595.2 1209.0 0.06 4234.7 0.52 TBV INLET 3595.2 1209.0 0.06 4234.7 0.52 TBV INLET 3595.2 1209.0 1.06 4234.7 0.52 TBV INLET 3595.2 1209.0 1.06 4234.7 0.52 02 TRB INLET 3595.2 1209.0 1.06 4234.7 0.52 02 TRB INLET 3595.2 1209.0 1.06 4234.7 0.52 02 TRB INLET 3595.1 1040.3 1.06 4140.6 0.48 H2 TRB INLET 3595.2 1009.0 1.06 4234.7 0.52 H2 TRB INLET 3540.7 1184.9 1.06 4140.6 0.48 H2 TRB INLET 3540.7 1184.9 1.06 4140.6 0.48 H2 TRB INLET 1641.7 1040.3 1.06 3595.0 0.28 H2 BST TRB IN 1625.3 1040.3 1.06 3595.0 0.28 H2 BST TRB IN 1625.3 1040.4 1.06 3595.0 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3580.4 0.27 H2 TANK PRESS 18.6 1036.7 1.06 3580.4 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 H2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 H2 TANK PRESS 18.6 1055.3 0.223 1810.7 0.49 H3KER OUT 1681.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1442.1 536.1 2.23 1810.7 0.49  |                  |             |            |           | -107.5   | 4.37    |
| B.P. EXIT 100.3 38.5 2.23 -103.0 4.39 PUMP INLET 100.3 38.5 2.23 13.7 4.30 1ST STAGE EXIT 1787.3 66.4 2.23 13.7 4.28 JBV INLET 1760.5 66.6 1.12 13.9 4.09 JBV INLET 1760.5 66.6 1.12 13.9 4.09 JBV EXIT 1696.4 68.6 1.12 13.9 4.09 PUMP EXIT 4981.0 137.3 1.12 298.4 3.98 PUMP EXIT 4981.0 137.3 1.12 298.4 3.96 COOLANT INLET 4931.2 137.7 1.12 298.4 3.96 COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 TBV EXIT 3240.7 1184.9 1.06 4140.6 0.48 PL TRB INLET 3240.7 1184.9 1.06 4140.6 0.48 PL TRB EXIT 3240.7 1184.9 1.06 4140.6 0.48 PL TRB EXIT 1657.5 1040.3 1.06 3595.0 0.29 PL TRB EXIT 1657.5 1040.3 1.06 3595.0 0.29 PL TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 PL TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 PL TRB DIFFUSER 1601.4 1038.0 1.06 3585.5 0.28 PL TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 PL TRB DIFFUSER 1601.4 1038.0 1.06 3585.5 0.28 PL TRB DIFFUSER 1667.5 1036.7 1.06 3580.4 0.27 OL BST TRB DUT 1575.6 1036.7 1. |                  |             |            |           | -103.0   | 4.39    |
| ST STAGE EXIT  |                  | -           |            |           | -103.0   | 4.39    |
| JBY INLET 1760.5 66.6 1.12 13.9 4.28  JBY INLET 1696.4 68.6 1.12 13.9 4.09  JBY EXIT 1696.4 68.6 1.12 164.0 4.05  JBY EXIT 4981.0 137.3 1.12 298.4 3.98  PUMP EXIT 4981.0 137.7 1.12 298.4 3.98  COOLANT INLET 6931.2 137.7 1.12 298.4 3.98  COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53  TBY INLET 3595.2 1209.0 0.06 4234.7 0.52  TBY EXIT 1567.0 1223.8 0.06 4234.7 0.52  TBY EXIT 1567.0 1223.8 0.06 4234.7 0.52  TBY EXIT 1567.0 1223.8 0.06 4234.7 0.52  TBY EXIT 3240.7 1184.9 1.06 4140.6 0.48  H2 TBR INLET 3240.7 1184.9 1.06 4140.6 0.48  H2 TBR EXIT 1657.5 1040.3 1.06 3595.0 0.29  H2 TBR EXIT 1641.7 1040.4 1.06 3595.0 0.28  H2 BST TRB DUT 1606.3 1038.0 1.06 3595.0 0.28  H2 BST TRB DUT 1606.3 1038.0 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.1 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.1 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28  H2 BST TRB DIFF 1601.4 1038.1 1.06 3580.4 0.27  H2 TANK PRESS 18.6 1056.7 1.06 3580.4 0.27  H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033  GOX HEAT EXCH DUT 1559.1 1045.4 1.12 3610.3 0.27  HIXER COLD IN 1559.1 1045.4 1.12 3610.3 0.27  HIXER COLD IN 1696.4 68.6 1.12 13.9 4.09  HIXER OUT 1612.2 535.9 2.23 1810.7 0.49  FSOV INLET 1481.2 535.9 2.23 1810.7 0.49  FSOV EXIT 1442.1 536.1 2.23 1810.7 0.49  FSOV EXIT 1442.7 536.2 2.23 1810.7 0.49   |                  |             |            |           | 13.7     | 4.30    |
| JBY INLE! 1696.4 68.6 1.12 13.9 4.09  JBY EXIT 1696.4 68.6 1.12 164.0 4.05  2ND STAGE EXIT 3673.0 104.6 1.12 298.4 3.98  PUMP EXIT 4981.0 137.3 1.12 298.4 3.98  COOLANT INLET 4931.2 137.7 1.12 298.4 3.96  COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53  TBY INLET 3595.2 1209.0 0.06 4234.7 0.52  TBY EXIT 1567.0 1223.8 0.06 4234.7 0.23  TBY EXIT 1567.0 1223.8 0.06 4234.7 0.52  CO TRB INLET 3595.2 1209.0 1.06 4234.7 0.52  TBY EXIT 1240.7 1184.9 1.06 4140.6 0.48  HZ TRB INLET 3240.7 1184.9 1.06 4140.6 0.48  HZ TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28  HZ TRB DIFFUSCR 1641.7 1040.4 1.06 3595.0 0.28  HZ BST TRB DIFF 1601.4 1038.0 1.06 3595.0 0.28  HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28  HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28  HZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27  OZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27  OZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27  GOX HEAT EXCH IN 1559.1 1045.4 1.12 3610.3 0.27  HIMER HOT IN 1559.1 1045.4 1.12 3610.3 0.27  HIMER HOT IN 1559.1 1045.4 1.12 3610.3 0.27  HIMER COLD IN 1696.4 68.6 1.12 13.9 4.09  HIXER OUT 1681.2 535.9 2.23 1810.7 0.49  FSOV INLET 1481.2 535.9 2.23 1810.7 0.48  FSOV EXIT 1422.7 536.2 2.23 1810.7 0.48   |                  |             |            |           | 13.9     | 4.28    |
| SIND STAGE EXIT 3473.0 104.6 1.12 164.0 4.05 PUMP EXIT 4981.0 137.3 1.12 298.4 3.98 PUMP EXIT 4981.0 137.3 1.12 298.4 3.96 COOLANT INLET 4931.2 137.7 1.12 298.4 3.96 COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53 TBV INLET 3595.2 1209.0 0.06 4234.7 0.52 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 02 TRB INLET 3595.2 1209.0 1.06 4234.7 0.52 02 TRB EXIT 3240.7 1184.9 1.06 4140.6 0.48 HZ TRB INLET 3240.7 1184.9 1.06 4140.6 0.48 HZ TRB EXIT 1657.5 1040.3 1.06 3595.0 0.29 HZ TRB EXIT 1657.5 1040.3 1.06 3595.0 0.29 HZ TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 HZ BST TRB IN 1625.3 1040.4 1.06 3595.0 0.28 HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 UZ BST TRB IN 1585.4 1038.1 1.06 3585.5 0.28 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1056.7 1.06 358 |                  |             |            |           | 13.9     | 4.09    |
| 2ND STABLE EXIT 4981.0 137.3 1.12 298.4 3.98 PUMP EXIT 4981.0 137.3 1.12 298.4 3.96 COOLANT INLET 6931.2 137.7 1.12 298.4 3.96 COOLANT INLET 6931.2 137.7 1.12 4234.7 0.53 TBV INLET 3695.2 1209.0 0.06 4234.7 0.52 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 TBV EXIT 1567.0 1263.8 0.06 4234.7 0.52 TBV EXIT 1567.0 1184.9 1.06 4140.6 0.48 TBV EXIT 1567.5 1040.3 1.06 3595.0 0.29 TBV EXIT 1657.5 1040.3 1.06 3595.0 0.28 TBV EXIT 1657.5 1040.4 1.06 3595.0 0.28 TBV EXIT 1661.7 1040.4 1.06 3595.0 0.28 TBV EXIT 1606.3 1038.0 1.06 3595.0 0.28 TBV EXIT 1601.4 1038.0 1.06 3595.5 0.28 TBV EXIT 1601.4 1038.0 1.06 3585.5 0.28 TBV EXIT 1601.4 1038.1 1.06 3580.4 0.27 TBV EXIT 1601.4 1038.1 1.06 3580.4 0.27 TBV EXIT 1601.4 1036.7 1.06 3580.4 0.27 TBV EXIT 1604.4 1.12 3610.3 0.27 TBV EXIT 1605.4 1.12 3610.7 0.49 TBV EXIT 1604.4 1.536.1 2.23 1810.7 0.49 TBV EXIT 1604.1 1559.1 1045.4 1.12 3610.3 0.27 TBV EXIT 1604.1 1559.1 1045.4 1.12 3610.3 0.27 TBV EXIT 1604.4 1536.1 2.23 1810.7 0.49 TBV EXIT 1604.1 1559.1 1045.4 1.12 3610.3 0.27 TBV EXIT 1604.4 1536.1 2.23 1810.7 0.49 TBV EXIT 1604.4 1536.1 2.23 1810.7 0.49 TBV EXIT 1604.4 1536.1 2.23 1810.7 0.49 TBV EXIT 1604.4 1536.2 2.23 1810.7  |                  |             |            |           | 164.0    | 4.05    |
| COOLANT IMLET 4931.2 137.7 1.12 298.4 3.96 COOLANT IMLET 4931.2 127.7 1.12 298.4 3.96 COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53 TBV IMLET 3595.2 1209.0 0.06 4234.7 0.23 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.23 OZ TRB INLET 3595.2 1209.0 1.06 4234.7 0.52 CZ TRB EXIT 3240.7 1184.9 1.06 4140.6 0.48 HZ TRB INLET 3240.7 1184.9 1.06 4140.6 0.48 HZ TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28 HZ TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28 HZ TRB DIFFUSEX 1641.7 1040.4 1.06 3595.0 0.28 HZ BST TRB DIF 1601.4 1038.0 1.06 3595.0 0.28 HZ BST TRB DUT 1606.3 1038.0 1.06 3595.5 0.28 HZ BST TRB DUT 1575.6 1038.0 1.06 3585.5 0.28 HZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 UZ BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 UZ BST TRB DUT 1575.6 1036.7 1.06 3580.4 0.27 UZ BST TRB DUT 1575.6 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 UZ BST TRB DIFF 159.1 1045.4 1.12 3610.3 0.27 HZ TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 GOX HEAT EXCH DN 1559.1 1045.4 1.12 3610.3 0.27 HIXER OUT 1 1559.1 1045.4 1.12 3610.3 0.27 HIXER COLD IN 1696.4 68.6 1.12 13.9 4.09 HIXER OUT 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1442.7 536.1 2.23 1810.7 0.49 FSOV EXIT 1442.7 536.2 2.23 1810.7 0.48  |                  |             |            |           | 298.4    | 3.98    |
| COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53 COOLANT EXIT 3631.6 1208.7 1.12 4234.7 0.53 TBV INLET 3595.2 1209.0 0.06 4234.7 0.52 TBV EXIT 1567.0 1223.8 0.06 4234.7 0.52 CTB INLET 3595.2 1209.0 1.06 4234.7 0.52 CTB INLET 3595.2 1209.0 1.06 4234.7 0.52 CTB EXIT 3240.7 1184.9 1.06 4140.6 0.48 CTB INLET 3240.7 1184.9 1.06 4140.6 0.48 CTB INLET 3240.7 1184.9 1.06 4140.6 0.48 CTB INLET 3240.7 1184.9 1.06 3595.0 0.29 CTB EXIT 1657.5 1040.3 1.06 3595.0 0.29 CTB EXIT 1657.5 1040.3 1.06 3595.0 0.29 CTB EXIT 1657.5 1040.4 1.06 3595.0 0.28 CTB INLET 1665.3 1040.4 1.06 3595.0 0.28 CTB INLET 1665.3 1040.4 1.06 3595.0 0.28 CTB INLET 1601.4 1038.0 1.06 3585.5 0.28 CTB INLET 1601.4 1038.0 1.06 3580.4 0.27 CTB INLET 1601.4 1036.7 1.06 3580.4  |                  |             |            |           | 298.4    | 3.96    |
| TBN INLET 3595.2 1209.0 0.06 4234.7 0.52 TBN EXIT 1567.0 1223.8 0.06 4234.7 0.52 TBN EXIT 1567.0 1223.8 0.06 4234.7 0.52 02 TRB INLET 3595.2 1209.0 1.06 4234.7 0.52 02 TRB EXIT 3240.7 1184.9 1.06 4140.6 0.48 H2 TRB INLET 3240.7 1184.9 1.06 4140.6 0.48 H2 TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28 H2 TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28 H2 TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 H2 BST TRB IN 1625.3 1040.4 1.06 3595.0 0.28 H2 BST TRB OUT 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 U2 BST TRB IN 1585.4 1038.1 1.06 3585.5 0.28 U2 BST TRB DIFF 1671.4 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.6 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.6 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1575.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1576.8 1036.7 1.06 3580 |                  |             |            | -         | 4234.7   | 0.53    |
| TBY INLET  184 TBLET  185 TBLET  1867.0 1223.8 0.06 4234.7 0.52  02 TRB INLET  3595.2 1209.0 1.06 4234.7 0.52  02 TRB EXIT  1240.7 1184.9 1.06 4140.6 0.48  12 TRB INLET  1240.7 1184.9 1.06 4140.6 0.48  12 TRB INLET  1657.5 1040.3 1.06 3595.0 0.28  12 TRB DIFFUSER  1641.7 1040.4 1.06 3595.0 0.28  12 TRB DIFFUSER  1641.7 1040.4 1.06 3595.0 0.28  12 BST TRB DIFF  1601.4 1038.0 1.06 3595.5 0.28  12 BST TRB DIFF  1601.4 1038.0 1.06 3585.5 0.28  12 BST TRB DIFF  1601.4 1038.0 1.06 3585.5 0.28  12 BST TRB DIFF  1601.4 1038.0 1.06 3585.5 0.28  12 BST TRB DIFF  1671.8 1036.7 1.06 3585.5 0.28  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1574.8 1036.7 1.06 3580.4 0.27  12 BST TRB DIFF  1559.1 1045.4 1.12 3610.3 0.27  13 MIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27  14 MIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27  14 MIXER OUT 1481.2 535.9 2.23 1810.7 0.49  15 MARER OUT 1481.2 535.9 2.23 1810.7 0.49  15 MARER INJ 1429.7 536.2 2.23 1810.7 0.48  15 CMARBER INJ 1429.7 536.2 2.23 1810.7 0.48   |                  |             |            |           |          | 0.52    |
| TBY EXIT 1567.0 1223.6 1.06 4234.7 0.52 02 TRB INLET 3595.2 1209.0 1.06 4140.6 0.48 120 120 120 120 120 120 120 120 120 120  |                  |             |            |           |          | 0.23    |
| 02 TRB INLET 3579.2 1293.0 1.06 4140.6 0.48 027 188 EXIT 3240.7 1184.9 1.06 4140.6 0.48 142 142 142 142 142 142 142 142 142 142  |                  |             |            |           |          | 0.52    |
| 02 TRB EXIT 3240.7 1184.9 1.06 4140.6 0.48 H2 TRB INLET 3240.7 1184.9 1.06 3595.0 0.29 H2 TRB EXIT 1657.5 1040.3 1.06 3595.0 0.28 H2 TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 H2 BST TRB IN 1625.3 1040.4 1.06 3595.0 0.28 H2 BST TRB DUT 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1036.7 1.06 3580.4 0.27 H2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.033 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 H3 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 HX TANK PRESS 18.6 1055.3 0.0017 3613.1 0.27 HX TANK PRESS 18.6 1055.3 0.0017 3613.1 0.27 HX TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 HX TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 HX TANK PRESS 18.6 1055.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27 HX TANK PRESS 18.6 1059.1 1045.4 1.12 3610.3 0.27  |                  |             |            |           |          | 0.48    |
| H2 TRB INLET 1240.7 1104.5 1.06 3595.0 0.29 H2 TRB EXIT 1657.5 1040.3 1.06 3595.0 0.29 H2 TRB DIFFUSER 1641.7 1040.4 1.06 3595.0 0.28 H2 BST TRB IN 1652.3 1040.4 1.06 3595.0 0.28 H2 BST TRB IN 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB IN 1585.4 1038.1 1.06 3585.5 0.28 0.28 ST TRB IN 1585.4 1038.1 1.06 3585.5 0.28 0.28 ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 0.28 ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 0.28 ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 0.28 ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 0.28 ST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 0.28 ST TRB DIFF 1574.8 1056.7 1.06 3580.4 0.27 0.29 0.29 0.29 0.29 0.29 0.29 0.29 0.29   |                  |             |            |           |          | 0.48    |
| H2 TRB EXIT 1657.5 1040.5 1.06 3595.0 0.28 H2 BST TRB IN 1625.3 1040.4 1.06 3595.0 0.28 H2 BST TRB OUT 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.1 1.06 3585.5 0.28 U2 BST TRB DIFF 1601.4 1038.1 1.06 3585.5 0.28 U2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 U2 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 U2 TRB DIFF 1564.4 1.12 3610.3 0.27 U2 TRB DIFF 1564.4 68.6 1.12 13.9 4.09 U2 TRB DIFF 1564.1 1481.2 535.9 2.23 1810.7 0.49 TRB DIFF 1564.1 1564.1 1536.1 2.23 1810.7 0.48 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.48 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.48 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1544.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1544.1 1542.7 536.2 2.23 1810.7 0.47 U2 TRB DIFF 1564.1 1544.1 15 |                  |             |            |           |          | 0.29    |
| H2 TRB DIFFUSCR 1641.7 1040.4 1.06 3595.0 0.28 H2 BST TRB DUT 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DUFF 1601.4 1038.0 1.06 3585.5 0.28 12 BST TRB DUFF 1601.4 1038.0 1.06 3585.5 0.28 12 BST TRB DUFF 1601.4 1038.0 1.06 3585.5 0.28 12 BST TRB DUFF 1574.8 1036.7 1.06 3580.4 0.27 12 BST TRB DUFF 1574.8 1036.7 1.06 3580.4 0.27 12 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 12 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 12 TANK PRESS 18.6 1059.3 0.0017 3613.1 0.27 12 TANK PRESS 18.6 10.27 12 TANK PRESS 18.6 10.2 12  |                  |             |            |           |          | 0.28    |
| H2 BST TRB IN 1606.3 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 102 BST TRB IN 1585.4 1038.1 1.06 3585.5 0.28 102 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 102 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 102 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 102 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 102 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27 102 TANK PRESS 18.6 102 TANK PRESS 18.6 10.2 TANK |                  |             |            |           |          | 0.28    |
| H2 BST TRB DUT 1601.4 1038.0 1.06 3585.5 0.28 H2 BST TRB DIFF 1601.4 1038.0 1.06 3585.5 0.28 OZ BST TRB 1N 1585.4 1038.1 1.06 3585.5 0.28 OZ BST TRB DUT 1575.6 1036.7 1.06 3580.4 0.27 OZ BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 GOX HEAT EXCH IN 1567.0 1046.1 1.12 3613.1 0.27 GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27 MIXER H0T IN 1559.1 1045.4 1.12 3610.3 0.27 MIXER COLD IN 1496.4 68.6 1.12 13.9 4.09 MIXER COULD IN 1496.4 68.6 1.12 13.9 4.09 MIXER OUT 1681.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48 CMANBER INJ 1429.7 536.2 2.23 1810.7 0.48   |                  |             |            |           |          | 0.28    |
| H2 BST TRB DIFF 1801.4 1038.1 1.06 3585.5 0.28 02 BST TRB DUT 1575.6 1036.7 1.06 3580.4 0.27 02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27 02 02 02 02 02 02 02 02 02 02 02 02 02  |                  | • • • • • • |            |           |          | 0.28    |
| 02 BST TRB IN 1585.4 1038.1 1.06 3580.4 0.27  02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27  02 BST TRB DIFF 1574.8 1036.7 1.06 3580.4 0.27  H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033  GOX HEAT EXCH IN 1567.0 1046.1 1.12 3610.3 0.27  GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27  HIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27  HIXER COLD IN 1496.4 68.6 1.12 13.9 4.09  HIXER COLD IN 1496.4 68.6 1.12 13.9 4.09  HIXER OUT 1681.2 535.9 2.23 1810.7 0.49  FSOV INLET 1481.2 535.9 2.23 1810.7 0.49  FSOV INLET 1464.1 536.1 2.23 1810.7 0.48  CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.67   | H2 BST TRB DIFF  | -           |            |           |          | 0.28    |
| O2 BST TRB OUT 1575.6 1036.7 1.06 3580.6 0.27 O2 BST TRB DIFF 1574.8 1036.7 1.06 3580.6 0.27 H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.0033 GOX HEAT EXCH IN 1547.0 1046.1 1.12 3610.3 0.27 GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27 MIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27 MIXER COLD IN 1496.4 68.6 1.12 13.9 4.09 MIXER COUT 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.47  |                  |             |            |           |          |         |
| O2 BST TRB DIFF 15/4.8 1055.7 0.0017 3613.1 0.0033   H2 TANK PRESS 18.6 1057.3 0.0017 3613.1 0.27   GOX HEAT EXCH IN 1567.0 1046.1 1.12 3610.3 0.27   GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27   HIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27   HIXER COLD IN 1496.4 68.6 1.12 13.9 4.09   HIXER OUT 1481.2 535.9 2.23 1810.7 0.49   FSOV INLET 1481.2 535.9 2.23 1810.7 0.49   FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48   CHARBER INJ 1429.7 536.2 2.23 1810.7 0.49   |                  |             |            |           |          |         |
| H2 TANK PRESS 18.6 1057.3 0.0017 GOX HEAT EXCH IN 1567.0 1046.1 1.12 3613.1 0.27 GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27 HIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27 HIXER COLD IN 1496.4 68.6 1.12 13.9 4.09 HIXER OUT 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1464.1 536.1 2.23 1810.7 0.48 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.47   | OZ BST TRB DIFF  |             |            |           |          | 0.0033  |
| GOX HEAT EXCH IN 1557.0 1045.1 1045.4 1.12 3610.3 0.27 GOX HEAT EXCH OUT 1559.1 1045.4 1.12 3610.3 0.27 MIXER HOT IN 1559.1 1045.4 1.12 3610.3 0.27 MIXER COLD IN 1496.4 68.6 1.12 13.9 4.09 MIXER OUT 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.67  |                  |             |            |           |          |         |
| GOX HEAT EXCH OUT 1559-1 1045-4 1.12 3610.3 0.27 HIXER HOT IN 1559-1 1045-6 1.12 3610.3 0.27 MIXER COLD IN 1496-6 68-6 1.12 13.9 4.09 MIXER OUT 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1444-1 536-1 2.23 1810.7 0.48 CHARBER INJ 1429-7 536-2 2.23 1810.7 0.47   |                  |             |            |           |          | 0.27    |
| MIXER HOT IN 1559.1 1045.4 1.12 13.9 4.09 MIXER COLD IN 1496.4 68.6 1.12 13.9 4.09 MIXER OUT 1481.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.49 FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.67  | GOX HEAT EXCH OU |             |            |           |          |         |
| MIXER COLD IN         1496.4         681.6         1.12         1.12         0.49           MIXER OUT         1481.2         535.9         2.23         1810.7         0.49           FSOV INLET         1481.2         535.9         2.23         1810.7         0.49           FSOV EXIT         1446.1         536.1         2.23         1810.7         0.48           CHAMBER INJ         1429.7         536.2         2.23         1810.7         0.67   | MIXER HOT IN     | 1559.1      |            |           |          |         |
| HIXER OUT 1681.2 535.9 2.23 1810.7 0.49 FSOV INLET 1481.2 535.9 2.23 1810.7 0.48 FSOV EXIT 1644.1 536.1 2.23 1810.7 0.47 CHARBER INJ 1429.7 536.2 2.23 1810.7 0.67   | MIXER COLD IN    |             |            |           |          |         |
| FSOV INLET 1481.2 535.9 2.23 1810.7 0.48 FSOV EXIT 1444.1 536.1 2.23 1810.7 0.48 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.47   | MIXER OUT        | 1481.2      |            |           |          | -       |
| FSDV EXIT 1444.1 536.1 2.23 1810.7 0.67 CHAMBER INJ 1429.7 536.2 2.23 1810.7 0.67  |                  | 1481.2      |            |           |          |         |
| CHAMBER INJ 1429.7 536.2 2.23 1810.7   |                  | 1444.1      |            |           |          |         |
|  |                  | 1429.7      | 536.2      | 2.23      | 1810.7   | 0.47    |
|  | CHAMBER          | 1329.9      |            |           |          |         |

|               | ■ DXYI | GEN SYSTEM |       | S •      | mes at 1 TM |
|---------------|--------|------------|-------|----------|-------------|
| STATION       | PRESS  | TEMP       | FLOH  | ENTHALPY | DENSITY     |
|               | 16.0   | 162.7      | 13.4  | 61.1     | 71.17       |
| B.P. INLET    |        | 163.2      | 13.4  | 61.5     | 71.20       |
| B.P. EXIT     | 135.6  |            | 13.4  | 61.5     | 71.20       |
| PUHP INLET    | 135.6  | 163.2      |       | 68.9     | 71.42       |
| PUMP EXIT     | 2153.8 | 173.7      | 13.4  |          | 0.12        |
| 02 TANK PRESS | 16.0   | 400.0      | 0.023 | 204.7    |             |
|               | 2132.3 | 173.B      | 13.4  | 68.9     | 71.39       |
| OCV INLET     |        | 176.2      | 13.4  | 68.9     | 70.38       |
| DCV EXIT      | 1492.6 |            |       | 68.9     | 70.34       |
| CHAMBER INJ   | 1462.9 | 176.3      | 13.4  | 00.7     |             |
| CHAMBER       | 1329.9 |            |       |          |             |

|             |         | VALVE DA | TA #  |          |
|-------------|---------|----------|-------|----------|
| VALVE       | DELTA P | AREA     | FLOH  | * BYPASS |
| 18A         | 264.    | 0.05     | 1.12  | 50.00    |
| TBV         | 2028.   | 0.00     | 0.06  | 5.00     |
|             | 37.     | 0.77     | 2.23  |          |
| FSOV<br>OCV | 640.    | 0.09     | 13.39 |          |

|          | •       | INJECTOR I | ATA # |            |
|----------|---------|------------|-------|------------|
| INJECTOR | DELTA P | AREA       | FLOM  | VELOC I TY |
| FUEL     | 100.    | 0.53       | 2.23  | 1288.81    |
| LOX      | 148.    | 0.21       | 13.39 | 132.35     |

TABLE 14. — SPLIT-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| *********                                     |   |
|---|---|
|   | HINERY PERFORMANCE DATA .                             |
|   | **************  |
| *************                                 |   |
| # HZ BOOST TURBINE #                          | # H2 MOOST PUMP *                                     |
| *************                                 | *************************                             |
| EFFICIENCY (T/T) 0.789                        |   |
| EFFICIENCY (T/S) 8,584                        | EFFICIENCY 0.766 HORSEPOHER 14.                       |
| SPEED (RPM) 75254.                            | SPEED (RPH) 75254.                                    |
| HEAN DIA (IN) 1.16<br>EFF AREA (IN2) 0.48     | \$ SPEED 3051.  |
| U/C (ACTUAL) 0.553                            |   |
| HAX TIP SPEED 484.                            | TIP SPEED 438.  |
| STAGES 1                                      |   |
|   | HEAD COEF 0.450 FLOW COEF 0.201                       |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02 | V.201   |
| HORSEPOHER 14.<br>EXIT MACH HUMBER 0.07       |   |
| SPECIFIC SPEED 128.86                         |   |
| SPECIFIC DIAMETER 0.68                        |   |
|   |   |
| ********                                      | 600000000   |
| # H2 TURBINE #                                | P H2 PUMP #   |
| *********                                     | **********  |
|   | STAGE ONE STAGE THO STAGE THREE                       |
| EFFICIENCY (T/T) 8.763                        | EFFICIENCY 0.617 0.699 0.517                          |
| EFFICIENCY (T/S) 0.750<br>SPEED (RPH) 187500. | PLUKSEPUMER 369. 238. 212.                            |
| HORSEPOHER #19                                | SPEED (RPH) 187500. 187500. 187500.<br>SS SPEED 9345. |
| HEAN DIA. (IN) 2.36<br>EFF AREA (IN2) 8.08    | P. PROCESS  |
| EFF AREA ([N2) 8.08<br>U/C (ACTUAL) 8.523     |   |
| MAX TIP SPEED 2000.                           | 2.39  |
| STAGES 2                                      | VOL. FLOM 233. 124, 126.                              |
| GAMMA 1.58 PRESS RATIO (T/T) 1.96             | HEAD COEF 8.520 0.489 0.453                           |
| PRESS RATIO (T/T) 1.96 PRESS RATIO (T/S) 1.98 | FLON COEF 0.096<br>DIAMETER BATIO 0.324               |
| EXIT MACH HUMBER 0.12<br>SPECIFIC SPEED 28.21 | MEARING DH 3.08E+06                                   |
| SPECIFIC SPEED 28.21 SPECIFIC DIAMETER 2.51   | SHAFT DIAMETER 16.00                                  |
| Sectific biaseign 2.51                        |   |
|   |   |
| = 02 BOOST TURBINE #                          |   |
| ************                                  | * 02 BOOST PLMP *                                     |
| EFFICIENCY (T/T) 0.811                        |   |
| EFFICIENCY (1/5) 0,739                        | EFFICIENCY 0.764 HORSEPONER 8.                        |
| SPEED (RPM) 20182.                            | SPEED (RPH) 20182.                                    |
| MEAN DIA (IN) 3.19<br>EFF AREA (IN2) 0.95     | \$ SPEED 3026.  |
| U/C (ACTUAL) 8,553                            | MEAD (FT) 262.<br>DIA. (IN) 1.69                      |
| MAX TIP SPEED 307.                            | 7 IP SPEED 152.                                       |
| STAGES 1                                      | VOL. FLON 85.   |
| PRESS RATIO (T/T) 1.01                        | HEAD COEF 0.450<br>FLOW COEF 0.200                    |
| PRESS RATIO (T/S) 1.01                        | 5.200   |
| HORSEPONER 8.                                 |   |
| EXIT MACH HUMBER 0.03<br>SPECIFIC SPEED 61.66 |   |
| SPECIFIC DIAMETER 1.29                        |   |
|   |   |
| *********                                     | 8530>>>==0  |
| * C2 TURBINE *                                | * 02 PUMP *   |
|   | *************   |
| EFFICIENCY (T/T) 0.772                        | EFFICIENCY 0.703                                      |
| EFFICIENCY (T/S) 0.743                        | HORSEPONER 141.                                       |
| SPEED (RPH) 112615.<br>HORSEPOHER 141.        | SPEED (RPH) 112615.                                   |
| MEAN DIA (IN) 2.36<br>EFF AREA (IN2) 0.12     | SS SPEED 20241.<br>S SPEED 2030.                      |
| EFF AREA (1H2) 0.12<br>U/C (ACTUAL) 0.535     | HEAD (FT) 4068,                                       |
| MAX TIP SPEED 1201.                           |   |
| STAGES 1                                      | TIP SPEED 565. VOL. FLON 84.                          |
| GAIPIA 1,58                                   | HEAD COEF 0.410                                       |
| PRESS RATIO (T/T) 1.11 PRESS RATIO (T/S) 1.11 | FLOW COEF 0.143                                       |
| EXIT MACH NUMBER 0.07 SPECIFIC SPEED 29.16    | DIAMETER RATIO 0.686<br>BEARING DN 1.58E+06           |
| SPECIFIC SPEED 29.16                          | SHAFT DIAMETER 14.00                                  |
| SPECIFIC DIAMETER 2.51                        |   |
|   |   |

TABLE 15. — SPLIT-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER)

| CHAMBER PRESSURE       | 1610.6 |
|------------------------|--------|
| VAC ENGINE THRUST      | 15000. |
| TOTAL ENGINE FLON RATE | 31.25  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 4.55   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 76.15  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C#                 | 0.993  |
| CHAMBER COOLANT DP     | 602.   |
| CHAMBER COOLANT DT     | 1121.  |
| NO 271 F/CHAMBER Q     | 9203.  |

|  |   | ********                              | *******                        | ••               |              |
|--|---|---------------------------------------|--------------------------------|------------------|--------------|
|  | - 6161                                  | SYSTEM COND                           | ITIONS *                       |                  |              |
|  | PDESS                                   | TEMP                                  | FLOH                           | ENTHALPY         | NATISHED     |
| STATION  | 18.6                                    | 37.4                                  | 4.47                           | -107.5           | 4.37         |
| B.P. INLET   | 100.3                                   | 38.5                                  | 4.47                           | -103.0           | 4.39         |
| B.P. EXIT  | 100.3                                   | 38.5                                  | 4.47                           | -103.0           | 4.39         |
| PUMP INLET 1ST STAGE EXIT JBV INLET JBV EXIT   | 2166.6                                  | 72.6                                  | 4.47                           | 40.2             | 4.29         |
| 151 STAGE EAST   | 2132.2                                  | 72.9                                  | 2.23                           | 40.2             | 4.27         |
| JBV EXIT   | 1812.3                                  | 75.2                                  | 2.23                           | 40.2             | 4.05         |
| 2ND STAGE EXIT   | 3476.6                                  | 95.3                                  | 2.23<br>2.23<br>2.23           | 136.0            | 4.25         |
| DIMO FYIT  | 4736.6                                  | 116.4                                 |                                | 227.4            | 4.26         |
| COOLANT INLET  | 4689.2                                  | 116.7                                 | 2.23                           | 227.4            | 4.24         |
| COOL ANT EXIT  | 4087.5                                  | 1237.4                                | 2.23                           | 4347.3           | 0.57         |
|  | 4046.6                                  | 1237.7                                | 0.11                           | 4347.3           | 0.57         |
| TBV EXIT   | 1898.0                                  | 1253.4<br>1237.7<br>1209.6<br>,1209.6 | 0.11                           | 4347.3           | 0.27         |
| 02 TRB INLET   | 4046.6                                  | 1237.7                                | 2.12                           | 4347.3           |              |
| OZ TRB EXIT  | 3594.2                                  | 1209.6                                | 2.12                           | 4236.6           | 0.52<br>0.52 |
| H2 TRB INLET   | 3594.2                                  | ,1209.6                               | 2.12                           | 4236.6           | 0.33         |
|  |   |                                       | 2.12                           | 3737.9           | 0.33         |
| HO TER DIFFUSER  | 1985.2                                  | 1078.9                                | 2.12                           | 3737.9           | 0.33         |
| H2 RST TRB IN  | 1965.4                                  | 1078.9                                | 2.12                           | 3737.9           | 0.32         |
| H2 BST TRB OUT   | 1943.9                                  | 1076.5                                | 2.12                           | 3728.4           | 0.32         |
| H2 BST TRB DIFF  | 1938.9                                  | 1076.5                                | 2.12                           | 3728-4           | 0.32         |
| 02 BST TRB IN  | 1919.5                                  | 1076.7                                | 2.12                           | 3728.4           | 0.32         |
| H2 TRB EXIT H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT H2 BST TRB DIFF O2 BST TRB OUT O2 BST TRB OUT | 1908.3                                  | 1075.3                                | 2.12                           | 3723.2           | 0.32         |
|  |   |                                       | 2.12<br>2.12<br>2.12<br>0.0033 | 3723.2<br>3754.4 | 0.0032       |
| H2 TANK PRESS  | 18.6                                    | 1097.9                                | 0.0033                         |                  | 0.32         |
| H2 TANK PRESS GOX HEAT EXCH IN GOX HEAT EXCH OU HIXER HOT IN HIXER COLD IN HIXER OUT FSOV INLET        | 1898.0                                  | 1084.3                                | 2.23                           | 3754.4           | 0.31         |
| GOX HEAT EXCH OU   | T 1888.5                                | 1083.6                                | 2.23                           | 3751.7           | 0.31         |
| MIXER HOT IN   | 1888.5                                  | 1083.6                                | 2.23                           | 3751.7<br>40.2   | 4.05         |
| MIXER COLD IN  | 1812.3                                  | 75.2                                  | 2.23                           | 1004 4           | 0.56         |
| MIXER OUT  | 1794.1                                  | 557.6                                 | 4.46                           | 1894.6           | 0.56         |
| FSOV INLET   | 1794.1                                  | 557.6                                 | 4.46                           |                  | 0.55         |
| FSOV INLET<br>FSOV EXIT  | 1749.3                                  | 557.8                                 | 4.46                           | 1894.6<br>1894.6 | 0.55         |
| CHAMBER INJ  | 1731.6                                  | 558.0                                 | 4.46                           | 1874.            | •            |
| CHAMBER  | 1731.6<br>1610.6                        |                                       |                                |                  |              |
|  |   |                                       |                                |                  |              |
|  | - 01                                    | YGEN SYSTEM                           | CONDITIONS                     |                  |              |
|  | 20F99                                   | TEMP                                  | FLON                           | ENTHALPY<br>61.1 | DENSITY      |
| STATION<br>B.P. INLET  | 16.0                                    | 162.7                                 | 26.8                           | 61.1             | 71-17        |
|  |   |                                       | 24 0                           | 61.5             | 71.20        |
| B.P. EXIT  | 135.6                                   | 163.2<br>163.2                        | 26.8                           | 61.5             | 71.20        |
| B.P. EXIT PUMP INLET PUMP EXIT 02 TANK PRESS OCY INLET   | 2608.5                                  | 175.2                                 | 26.8                           | 70.2             | 71.61        |
| PUMP EXII  | 16.0                                    | 400.0                                 | 0.045                          | 204.7            | 0.12         |
| OZ TARK FRESS  | 2582.4                                  | 175.3                                 | 26.8                           | 70.2             | 71.57        |
| OCV EXIT   | 1807.7                                  | 178.2                                 | 26.8                           | 70.2             | 70.36        |
| CHAMBER INJ  | 1771.7                                  | 178.4                                 | 26.B                           | 70.2             | 70.30        |
| CHAMBER  | 1610.6                                  |                                       |                                |                  |              |
| CAMPIDER   | • |                                       |                                |                  |              |
|  |   |                                       |                                |                  |              |
|  |   | . VALVE DA                            | ATA .                          | % BYPASS         |              |
| VALVE  | DELTA                                   | P AREA                                | FLUM                           | 50.00            |              |
| JBV  | DELTA 1<br>320<br>2149<br>45            | . 0.07                                | 4.23                           | 5.00             |              |
| TBV  | 2149                                    | . 0.01<br>. 1.30                      | 0.11                           | 3.00             |              |
| FSOV   | 45                                      | 1.30                                  | 4.46                           |                  |              |
| OCA  | 775                                     | 0.17                                  | 26.79                          |                  |              |
|  |   |                                       |                                |                  |              |
|  |   | # INJECTOR                            | DATA .                         |                  |              |
| INJECTOR   | DELTA                                   | P AREA<br>. 0.90                      | FLOM                           | VELOCITY         |              |
| FUEL   | 121                                     | 0.90                                  | 4.46                           | 1327.74          |              |
| LOX  | 179                                     | 0.38                                  | 26.79                          | 145.68           |              |
| 2011   |   |                                       |                                |                  |              |

TABLE 15. — SPLIT-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| THOMPORTUR #  | NERY PERFORMANCE DATA                                |   |
|---|--|---|
|   |  |   |
| ######################################  | *********  |   |
| P H2 BOOST TURBINE #  | * H2 BOOST P   |   |
|   |  |   |
| EFFICIENCY (T/T) 0.815<br>EFFICIENCY (T/S) 0.622  | EFFICIENCY   | 0.766                                   |
| SPEED (RPH) 53238.  | HORSEPOHER   | 28.                                     |
| MEAN DIA ATUS SAA   | SPEED (RPH)<br>S SPEED                               | 53238.<br>3050.                         |
| EFF AREA (IN2) ].18   | HEAD (FT)  | 2685.                                   |
| U/C (ACTUAL) 0.553  | HEAD (FT)<br>DIA. (IN)                               | 1.80                                    |
| MAX TIP SPEED 476.  | TIP SPEED  | 438.                                    |
| STAGES 1  | YOL. FLON  | 457.                                    |
| PRESS RATIO (T/T) 1.81  | HEAD COEF<br>FLOH COEF                               | 0.450                                   |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01   | rear coer  | 0.201                                   |
| HORSEPOHER 28.  |  |   |
| EXIT HACH HUMBER 0.86   |  |   |
| SPECIFIC SPEED 117.16<br>SPECIFIC DIAMETER 0.71   |  |   |
| SPECIFIC DIAMETER 0.71  |  |   |
|   |  |   |
| 01044148000000  | ********   |   |
| = H2 TURBINE =  | # H2 PUHP  |   |
|   | **************************************               |   |
|   |  | STAGE THO STAGE THREE                   |
| EFFICIENCY (T/T) 0.779  | EFFICIENCY 0.617                                     | 0.592 0.400                             |
| EFFICIENCY (T/S) 0.763  | HORSEPOHER 905.                                      | 303. 289.                               |
| HORSEPOLER  | EFFICIENCY 0.617 HORSEPOHER 905. SPEED (RPH) 136363. | 136363. 136363.                         |
| EFFICIENCY (T/S) 0.763<br>SPEED (RPH) 136363.<br>HORSEPONER 1697.<br>HEAN DIA. (IN) 3.26<br>EFF AREA (IN2) 0.15 |  |   |
| EFF AREA (IN2) 8.15   | S SPEED 694.<br>HEAD (FT) 68810.<br>DIA. (IN) 3.39   | 486. 705.<br>44229. 42620.<br>2.82 2.82 |
| U/C (ACTUAL) 0.548  | DIA. (IN) 3,39                                       | 2.82 2.82                               |
| MAX TIP SPEED 2000.   | 11 SPEED 2020.                                       | 1677. 1677.                             |
| STAGES 2 GAMMA 1.68   | YUL. FLUM 467.                                       | 236. 235.                               |
| PRESS RATIO (T/T) 1.79  | HEAD COEF 0.542<br>FLOH COEF 0.089                   | 0.506 0.480                             |
| PRESS RATIO (T/S) 1.82  | DIAMETER RATIO 0.304                                 |   |
| EXIT MACH NUMBER 0.12<br>SPECIFIC SPEED 29.04   | BEARING DN 3.00E+06                                  |   |
| SPECIFIC SPEED 29.04  | SHAFT DIAMETER 22.00                                 |   |
| SPECIFIC DIAMETER 2.57  |  |   |
|   |  |   |
| ***************************************   | =======================================              |   |
| = 02 BOOST TURBINE =  | P 02 BOOST PU  |   |
|   |  | ••••                                    |
| EFFICIENCY (T/T) 9.827  | EFFICIENCY   | 0.764                                   |
| EFFICIENCY (T/S) 8.759  | EFFICIENCY<br>HORSEPONER                             | 15.                                     |
| SPEED (RPH) 14271.  | SPEED (RPM)  | 14271.                                  |
| MEAN DIA (IN) 4.50<br>EFF AREA (IN2) 1.64   | S SPEED  | 3026.                                   |
|   | HEAD (FT)<br>DIA. (IN)                               | 242.<br>2.11                            |
| MAX TIP SPEED 305.  | TIP SPEED  | 132.                                    |
| STAGES 1  | VOL. FLOW  | 169.                                    |
| GAMMA 1.48  | HEAD COEF<br>FLOH COEF                               | 0.450                                   |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01   | FLOH COEF  | 0.200                                   |
| HORSEPOHER 15.  |  |   |
| EXIT MACH NUMBER 8.02   |  |   |
| SPECIFIC SPEED 58.28  |  |   |
| SPECIFIC DIAMETER 1.38  |  |   |
|   |  |   |
| BEREFERENCE B   | *********  |   |
| OZ TURBINE B  | = 02 PUP =   |   |
|   |  |   |
| EFFICIENCY (T/T) 0.779  | EFF ICIDICY  | 0.730                                   |
| EFFICIENCY (T/S) 8.755  | HORSEPOHER   | 332.                                    |
| SPEED (RPH) 85773.<br>HORSEPOHER 132.   | SPEED (RPH)  | 85773.                                  |
| MEAN DIA CINI T TA  | 2 25ED<br>22 25ED                                    | 21801.                                  |
| EFF AREA (IN2) 8.28   | 3 3 660  | 1879.<br>4971.                          |
| WC (ACTUAL) 0.518   | HEAD (FT)<br>DIA. (IN)                               | 1.65                                    |
| MAX TIP SPEED 1257.   | TIP SPEED  | 617.                                    |
| STAGES 1  | VOL. FLON  | 160.                                    |
| PRESS RATIO (T/T) 1.13  | HEAD COEF  | 0.420                                   |
| PRESS RATIO (T/T) 1.13 PRESS RATIO (T/S) 1.13   | FLOW COEF  | 0.157                                   |
| EXIT MACH NUMBER 0.07   | DIAMETER RATIO<br>BEARING DN 1.                      | 0.683<br>37F+06                         |
| SPECIFIC SPEED 26.93  | SHAFT DIAMETER                                       | 16.00                                   |
| SPECIFIC DIAMETER 2.64  |  |   |
|   |  |   |

TABLE 16. — SPLIT-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER)

| CHAMBER PRESSURE       | 1712.8 |
|------------------------|--------|
| VAC FNGINE THRUST      | 25000. |
| TOTAL ENGINE FLOW RATE | 52.08  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 7.14   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 95.35  |
| FIGURE MIXTURE RATIO   | 6.00   |
| ETA Cª                 | 0.993  |
| CHAMBER COOLANT DP     | 616.   |
| CHAMBER COOLANT DT     | 1010.  |
| NOZZLE/CHAMBER Q       | 13870. |

|                                   | ******** | *******        | *********    |                  |              |
|-----------------------------------|----------|----------------|--------------|------------------|--------------|
|                                   | # EUE1 9 | SYSTEM CON     | * ZMOLTIO    |                  |              |
|                                   | PRESS    | TEMP           | FLOH         | ENTHALPY         | DENSITY      |
| STATION<br>B.P. INLET             | 18.6     | 37.4           | 7.45         | -107.5           | 4.37         |
| B.P. EXIT                         | 101.2    | 38.5           | 7.45         | -103.0           | 4.39         |
| PUMP INLET                        | 101.2    | 38.5           | 7.45         | -103.0           | 4.39         |
| 1ST STAGE EXIT                    | 2301.9   | 70.0           | 7.45         | 36.1             | 4.42         |
|                                   | 2267.4   | 70.3           | 3.72         | 36.1             | 4.40         |
| JBV EXIT                          | 1927.3   | 73.0           | 3.72         | 36.1             | 4.17         |
| 2ND STAGE EXIT                    | 3708.6   | 90.5           | 3.72         | 127.7            | 4.43         |
| PUMP EXIT                         | 5091.3   | 110.0          | 3.72         | 216.8            | 4.47<br>4.45 |
| COOLANT INLET                     | 5040.4   | 110.4          | 3.72         | 216.8            | 0.67         |
| COOLANT EXIT                      | 4424.2   | 1119.9         | 3.72         | 3942.2           | 0.67         |
| TBV INLET                         | 4379.9   | 1120.2         | 0.19         | 3942.2<br>3942.2 | 0.32         |
| TBV EXIT                          |          | 1137-1         | 0.19         | 3942.2           | 0.67         |
| 02 TRB INLET                      | 4379.9   | 1120.2         | 3.54<br>3.54 | 3827.0           | 0.61         |
|                                   | 3864.7   | 1091.1         | 3.54         | 3827.0           | 0.61         |
|                                   |          | 1091.1         | 3.54         | 3343.9           | 0.39         |
| H2 TRB EXIT                       | 2134.2   | 965.0<br>965.1 | 3.54         | 3343.9           | 0.39         |
| H2 TRB DIFFUSER                   | 2113.7   | 965.1          | 3.54         | 3343.9           | 0.39         |
|                                   | 2092.6   | 965.1<br>962.7 | 3.54         | 3334.3           | 0.38         |
| H2 BST TRB OUT<br>H2 BST TRB DIFF |          | 962.7          | 3.54         | 3334.3           | 0.38         |
| OZ BST TRB IN                     | 2042.9   | 962.9          | 3.54         | 3334.3           | 0.38         |
|                                   | 2030.2   | 961.5          | 3.54         | 3329.2           | 0.38         |
| 02 BST TRB DIFF                   | 2029.4   | 961.5          | 3.54         | 3329.2           | 0.38         |
| H2 TANK PRESS                     | 18.6     | 984.3          | 0.0061       | 3359.8           | 0.0036       |
| GOX HEAT EXCH IN                  |          | 970.3          | 3.72         | 3359.B           | 0.37         |
| GOX HEAT EXCH OUT                 |          | 969.6          | 3.72         | 3357.1           | 0.37         |
| MIXER HOT IN                      |          | 969.6          | 3.72         | 3357.1           | 0.37         |
|                                   | 1927.3   | 73.0           | 3.72         | 36.1             | 4.17         |
| MIXER DUT                         | 1908.7   | 502.4          | 7.44         | 1695.3           | 0.66         |
| FSOV INLET                        | 1908.7   | 502.4          | 7.44         | 1695.3           | 0.66         |
| FSOV EXIT                         | 1861.0   | 502.6          | 7.44         | 1695.3           | 0.65<br>0.64 |
| CHAMBER INJ                       | 1842.6   | 502.7          | 7.44         | 1695.3           | 0.44         |
| CHAMBER                           | 1712.8   |                |              |                  |              |
|                                   |          |                |              |                  |              |
|                                   | # 0XV    | SEN SYSTEM     | CONDITION    | s •              |              |
| STATION                           | PRESS    | TEMP           | FLON         | ENTHALPY         | DENSITY      |
| B.P. INLET                        | 16.0     | 162.7          | 44.7         | 61.1             | 71.17        |
| B.P. EXIT                         | 135.6    | 163.2          | 44.7         | 61.5             | 71.20        |
| PUMP INLET                        | 135.6    | 163.2          | 44.7         | 61.5             | 71.20        |
| PUMP EXIT                         | 2773.9   | 175.4          | 44.7         | 70.6             | 71.73        |
| D2 TANK PRESS                     | 16.0     | 400.0          | 0.076        | 204.7            | 0.12         |
| 02 TANK PRESS                     | 2746.2   | 175.5          | 44.6         | 70.6             | 71.68        |
| OCV EXIT                          | 1922.3   | 178.7          | 44.6         | 70.6             | 70.40        |
| CHAMBER INJ                       | 1884.l   | 178.8          | 44.6         | 70.6             | 70.34        |
| CHAMBER                           | 1712.8   |                |              |                  |              |
|                                   |          |                |              |                  |              |
|                                   |          | . VALVE DA     | TA =         |                  |              |
| MAL ME                            | DELTA P  |                | FLOH         | * BYPASS         |              |
| JBV<br>JBV                        | 340.     |                | 3.72         | 50.00            |              |
| TBV                               | 2361.    | 0.01           | 0.19         | 5,00             |              |
| FSOV                              | 48.      | 1.93           | 7.44         |                  |              |
| DCV                               | 824.     |                | 44.64        |                  |              |
| - <del></del> -                   |          |                |              |                  |              |
|                                   | _        | INJECTOR       | DATA #       |                  |              |
|                                   | DEL TA D | AREA           | FLO≌         | VELOC! TY        |              |
| INJECTOR                          | DELIA P  | 1.33           | 7.44         | 1274.82          |              |
| FUEL.                             | 130.     |                |              | 150.19           |              |
| FOX                               | 170.     | J. V.          |              |                  |              |

TABLE 16. — SPLIT-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| TURBONACHI  | HERY PERFORMANCE DATA B                     |                              |  |  |  |
|---|---|------------------------------|--|--|--|
|   |   |                              |  |  |  |
| # H2 BOOST TURBINE #  | **************************************      |                              |  |  |  |
|   | - 15 20031 1                                |                              |  |  |  |
| EFFICIENCY (T/T) 8.873  | EFF101ENCY                                  | 0.765                        |  |  |  |
| EFFICIENCY (T/S) 0.484  | HORSEPONER                                  | 48.                          |  |  |  |
| SPEED (RPH) 41431,<br>MEAH DIA (1H) 2.12                          | SPEED (RPH)<br>S SPEED                      | 41431.<br>3042.              |  |  |  |
| EFF AREA (1M2) 1.70   | HEAD (FT)                                   | 2712.                        |  |  |  |
| U/C (ACTUAL) 0.553<br>HAX TIP SPEED 471.                          | DIA. (IN)<br>TIP SPEED                      | 2.43<br>440.                 |  |  |  |
| STAGES 1  | VOL. FLOH                                   | 761.                         |  |  |  |
| GAMMA 1.44 PRESS RATIO (T/T) 1.61                                 | HEAD COEF<br>FLOH COEF                      | 0.450<br>0.200               |  |  |  |
| PRESS RATIO (T/S) 1.01  | TEM COD                                     | 0.200                        |  |  |  |
| HORSEPOHER 68.<br>EXIT MACH HUMBER 8.06                           |   |                              |  |  |  |
| SPECIFIC SPEED 114.95   |   |                              |  |  |  |
| SPECIFIC DIMETER 0.75   |   |                              |  |  |  |
|   |   |                              |  |  |  |
| • H2 TURBINE *  | * H2 PUMP                                   |                              |  |  |  |
| *********   | *******                                     | ••                           |  |  |  |
|   | STAGE ONE                                   | STAGE THO STAGE THREE        |  |  |  |
| EFFICIENCY (T/T) 0.828  | EFFICIENCY 0.664                            | 0.642 0.645                  |  |  |  |
| EFFICIENCY (T/S) 0.812<br>SPEED (RPH) 125000.<br>HORSEPOMER 2418. | HORSEPONER 1465.<br>SPEED (RPH) 125000.     | 483. 478.<br>125000. 125000. |  |  |  |
| HORSEPONER 2418.  | 22 2PEED 11287.                             |                              |  |  |  |
| MEAN DIA. (IN) 3.16<br>EFF AREA (IN2) 8.21                        | S SPEED 783.<br>HEAD (FT) 71837,            | 776. 786.<br>45767. 44733.   |  |  |  |
| U/C (ACTUAL) 0.495<br>MAX TIP SPEED 1000.                         | DIA. (IN) 3.79                              | 3.09 3.09                    |  |  |  |
| STAGES 2  | TIP SPEED 2066.<br>VOL. FLON 756.           | 1688. 1688.<br>377. 374.     |  |  |  |
| POECE DATIO (T/T) 1 AL  | HEAD COEF 8.541<br>FLOH COEF 8.096          | 0.517 0.505                  |  |  |  |
| PRESS RATIO (T/S) 1.83  | DIMETER RATIO 8.333                         |                              |  |  |  |
| EXIT MACH NUMBER 8,12   | SEARING DN 3.00E+06<br>SHAFT DIAMETER 24,00 |                              |  |  |  |
| SPECIFIC DIMETER 2.10   | SHAFT DIAMETER 24.00                        |                              |  |  |  |
|   |   |                              |  |  |  |
| * 02 BOOST TURBINE *  | P*************************************      |                              |  |  |  |
| ************************  | * 02 BOOST PU                               |                              |  |  |  |
| EFFICIENCY (T/T) 8.869  | EFF1C1ENCY                                  | 0.764                        |  |  |  |
| EFFICIENCY (T/S) 0.802  | HORSEPOHER                                  | 26.                          |  |  |  |
| SPEED (RPH) 11055.<br>MEAN DIA (IH) 5.82                          | SPEED (RPH)<br>S SPEED                      | 11055.<br>3026.              |  |  |  |
| EFF AREA (1H2) 2.36   | HEAD (FT)                                   | 242.                         |  |  |  |
| U/C (ACTUAL) 8.553<br>MAX TIP SPEED 302.                          | DIA. (IN)<br>TIP SPEED                      | 2.72<br>132.                 |  |  |  |
| STAGES 1  | VOL. FLON                                   | 282.                         |  |  |  |
| GAMMA 1.44<br>PRESS RATIO (T/T) 1.01                              | HEAD COEF<br>FLON COEF                      | 0.450<br>0.200               |  |  |  |
| PRESS RATIO (T/S) 1.81<br>HORSEPOHER 24.                          |   | *****                        |  |  |  |
| EYTT MACH HINDER A AS   |   |                              |  |  |  |
| SPECIFIC SPEED 55.64 SPECIFIC DIAMETER 1.47                       |   |                              |  |  |  |
| SPECIFIC DIAMETER 1.47  |   |                              |  |  |  |
| *********   | *********                                   |                              |  |  |  |
| . 02 TURBINE .  | • 02 PUMP =                                 |                              |  |  |  |
| *********   | **********                                  |                              |  |  |  |
| EFFICIENCY (T/T) 0.850  | EFFICIENCY                                  | 0.747                        |  |  |  |
| EFFICIENCY (T/S) 0.825<br>SPEED (RPH) 67789.                      | HORSEPOHER<br>SPEED (RPM)                   | 576.                         |  |  |  |
| HORSEPOHER 576.   | SC SPEED                                    | 67789.<br>22244.             |  |  |  |
| MEAN DIA (IN) 3,16<br>EFF AREA (IN2) 0.29                         | S SPEED<br>HEAD (FT)                        | 1827.                        |  |  |  |
| U/C (ACTUAL) 0,550  | DIA. (IN)                                   | 5295.<br>2.14                |  |  |  |
| MAX TIP SPEED 984.<br>STAGES 2                                    | TIP SPEED<br>VOL. FLON                      | 632.                         |  |  |  |
| GAHMA 1.44  | HEAD COEF                                   | 280.<br>0.426                |  |  |  |
| PRESS RATIO (T/T) 1.13 PRESS RATIO (T/S) 1.14                     | FLOW COEF                                   | 0.155                        |  |  |  |
| EXIT MACH NUMBER 0.07   | DIAMETER RATIO<br>BEARING DH 1              | 0.682<br>.49E+06             |  |  |  |
| SPECIFIC SPEED 42.69 SPECIFIC DIAMETER 1.85                       | SHAFT DIAMETER                              | 22.00                        |  |  |  |
| 1.83  |   |                              |  |  |  |
|   |   |                              |  |  |  |

TABLE 17. — SPLIT-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER)

| CHAMBER PRESSURE       | 1608.0 |
|------------------------|--------|
| VAC ENGINE THRUST      | 37500. |
| TOTAL ENGINE FLON RATE | 78.12  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 11.40  |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 120.49 |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C#                 | 0.993  |
| CHAMBER COOLANT DP     | 547.   |
| CHAMBER COOLANT DT     | 879.   |
| NOZZLE/CHAMBER Q       | 18214. |

|  | *********        |                              |   | •••              |                |
|--|------------------|------------------------------|---|------------------|----------------|
|  | # EUEL !         | SYSTEM CON                   | DITIONS =                               |                  |                |
| STATION  | PRESS            | TEMP                         | FLOH                                    | ENTHALPY         | DENSITY        |
| B.P. INLET   | 18.6             | 37.4                         | 11.17                                   | -107.5           | 4.37           |
| B.P. EXIT  | 100.9            | 38.5                         | 11.17                                   | -103.0           | 4.39           |
| PUMP INLET   | 100.9            | 38.5                         | 11.17                                   | -103.0           | 4.39           |
| IST STAGE EXIT                                     | 2161-1           | 65.1                         | 11.17                                   | 19.4             | 4.49           |
| JBV INLET  | 212B.7           | 65.4                         | 5.59                                    | 19.5             | 4.47           |
| JBV EXIT   | 1809.4           | 68.2                         | 5.59                                    | 19.5             | 4.26<br>4.54   |
| 2ND STAGE EXIT                                     | 3418.3           | 81.1                         | 5.59                                    | 94.6<br>168.6    | 4.59           |
| PUMP EXIT  | 4672.0           | 96.6<br>97.0                 | 5.59<br>5.59                            | 168.6            | 4.57           |
| COOLANT INLET                                      | 4625.3<br>4078.0 | 976.2                        | 5.59                                    | 3429.6           | 0.71           |
| COOLANT EXIT                                       | 4037.2           | 976.4                        | 0.28                                    | 3429.6           | 0.71           |
| TBV EXIT   | 1895.0           | 991.2                        | 0.28                                    | 3429.6           | 0.34           |
| 02 TRB INLET                                       | 4037.2           | 976.4                        | 5.31                                    | 3429.6           | 0.71           |
| OZ TRB EXIT  | 3542.2           | 949.6                        | 5.31                                    | 3323.8           | 0.64           |
| H2 TRB INLET                                       | 3542.2           | 949.6                        | 5.31                                    | 3323.8           | 0.64           |
| H2 TRB EXIT  | 2012.1           | 841.7                        | 5.31                                    | 2908.9           | 0.43<br>0.42   |
| H2 TRB DIFFUSER                                    |                  | 841.8                        | 5.31                                    | 2908.9<br>2908.9 | 0.42           |
| H2 BST TRB IN                                      | 1968.8           | 841.8                        | 5.31                                    | 2899.3           | 0.41           |
| H2 BST TRB OUT                                     | 1943.3           | 839.4                        | 5.31<br>5.31                            | 2899.3           | 0.41           |
| H2 BST TRB DIFF                                    | 1938.3           | 839.5<br>839.6               | 5.31                                    | 2899.3           | 0.41           |
| 02 BST TRB IN                                      | 1918.9<br>1905.3 | 979 2                        | 5.31                                    | 2894.2           | 0.41           |
| 02 BST TRB OUT<br>02 BST TRB DIFF<br>H2 TANK PRESS | 1904.5           | 838.2                        | 5.31<br>0.0105                          | 2894.2           | 0.41           |
| H2 TANK PRESS                                      | 18.6             | 857.9                        | 0.0105                                  | 2921.0           | 0.0041         |
| GOX HEAT EXCH IN                                   |                  | 845.8                        | 5.58                                    | 2921.0           | 0.40           |
| GOX HEAT EXCH DU                                   |                  | 845.1                        | 5.58                                    | 2918.2           | 0.40           |
| MIXER HOT IN                                       | 1885.5           | 845.1                        | 5.58                                    | 2918.2           | 0.40           |
| HIXER COLD IN                                      | 1809.4           | 68.2                         | 5.59                                    | 19.5             | 4.26           |
| MIXER OUT  | 1791.2           | 441.3                        | 11.16                                   | 1467.5           | 0.70           |
| FSOV INLET   | 1791.2           | 441.3                        | 11.16                                   | 1467.5           | 0.70<br>0.69   |
| FSOV EXIT  | 1746.5           | 441.4                        | 11.16                                   | 1467.5<br>1467.5 | 0.68           |
| CHAMBER INJ  | 1728.8           | 441.5                        | 11.16                                   | 1407.3           | *              |
| CHAMBER  | 1608.0           |                              |   |                  |                |
|  |                  |                              |   |                  |                |
|  | # OXY0           | EN SYSTEM                    | CONDITION                               | S •              |                |
| STATION  | PRESS            | TEMP                         | FLOM                                    | ENTHALPY         | DENSITY        |
| B.P. INLET   | 16.0             | 162.7                        | 67.1                                    | 61.1             | 71.17          |
| B.P. EXIT  | 135.6            | 163.2                        | 67.1                                    | 61.5             | 71.20<br>71.20 |
| PUMP INLET   | 135.6            | 163.2                        | 67.1                                    | 61.5             | 71.75          |
| PUMP EXIT  | 2604.2           | 174.3                        | 67.1                                    | 69.8<br>204.7    | 0.12           |
| 02 TANK PRESS                                      | 16.0             | 400.0                        | 0.113<br>67.0                           | 69.8             | 71.71          |
| OCV INLET  | 2578.2           | 174.4<br>177.3               | 67.0                                    | 69.8             | 70.51          |
| DCV EXIT   | 1804.7<br>1768.8 | 177.4                        | 67.0                                    | 69.8             | 70.45          |
| CHAMBER INJ<br>CHAMBER                             | 1608.0           | 177                          | • |                  |                |
| CHARIBER   | 1000.0           |                              |   |                  |                |
|  |                  |                              |   |                  |                |
|  |                  | <ul> <li>VALVE DA</li> </ul> |   |                  |                |
| VALVE  | DELTA P          |                              | FLON                                    |                  |                |
| JBV  | 319.             |                              | 5.59                                    | 50.00            |                |
| VET  | 2142.            | 0.02                         | 0.28                                    | 5.00             |                |
| FSOV   | 45.              | 2.90                         | 11.16                                   |                  |                |
| ocv  | 773.             | 0.43                         | 66.96                                   |                  |                |
|  |                  |                              |   |                  |                |
|  |                  | INJECTOR                     |   |                  |                |
| INJECTOR   | DELTA P          | AREA                         | FLON                                    |                  |                |
| FUEL   | 121.             | 2.00                         | 11.16                                   |                  |                |
| LOX  | 179.             | 0.94                         | 66.96                                   | 145.41           |                |
|  |                  |                              |   |                  |                |

TABLE 17. — SPLIT-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|  | **************                              |                            |
|--|---|----------------------------|
|  | HERY PERFORMANCE DATA *                     |                            |
| *************                                    | *********                                   | ****                       |
| * H2 BOOST TURBINE #                             | * H2 BOOST P                                |                            |
| EFFICIENCY (T/T) 0.884                           | EFFICIENCY                                  | 0.765                      |
| EFFICIENCY (T/S) 0.701<br>SPEED (RPM) 33776,     | HORSEPOHER<br>SPEED (RPM)                   | 72.<br>33776.              |
| MEAN DIA (IN) 2.60                               | S SPEED                                     | 3044.                      |
| EFF AREA (IN2) 2.39<br>U/C (ACTUAL) 8.55%        | HEAD (FT)<br>DIA. (IN)                      | 2704.<br>2.98              |
| MAX TIP SPEED 467.                               | TIP SPEED                                   | 440.                       |
| STAGES 1 GAMMA 1.41                              | VOL. FLOW                                   | 1142.                      |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02    | HEAD COEF<br>FLOW COEF                      | 0.450<br>0.201             |
| PRESS RATIO (T/S) 1.02<br>HORSEPOMER 72,         |   |                            |
| EXIT MACH MUMBER 0.07<br>SPECIFIC SPEED 112.96   |   |                            |
| SPECIFIC SPEED 112.96                            |   |                            |
| SPECIFIC DIAMETER 0.77                           |   |                            |
| * H2 TURBINE *                                   | 9490948P01                                  |                            |
| - IZ TORBINE S                                   | * H2 PUMP                                   |                            |
|  | STAGE ONE                                   | STAGE THO STAGE THREE      |
| EFFICIENCY (T/T) 0.851                           | EFFICIENCY 0.697                            | 8.686 0.686                |
| EFF1CIENCY (T/S) 0.829                           | HORSEPOHER 1936.                            | COL COC                    |
| SPEED (RPH) 107143.<br>HORSEPOMER 3115.          | SPEED (RPM) 107143.<br>SS SPEED 11876.      | 107143. 107143.            |
| MEAN DIA. (IM) 3.70<br>EFF AREA (1M2) 0.33       |   | 889. 893.<br>40081. 39544. |
| U/C (ACTUAL) 0.536                               | HEAD (FT) 66458.<br>DIA. (IN) 6.26          |                            |
| MAX TIP SPEED 1812.                              | TIP SPEED 1992.                             | 1577. 1578.                |
| STAGES 2 GAMMA 1.41                              | VOL. FLON 1116.<br>HEAD COEF 0.539          | 553. 546.                  |
| PRESS RATIO (T/T) 1.76                           | FLOH COEF 0.102                             | 0.518 0.511                |
| PRESS RATIO (T/S) 1.79<br>EXIT MACH NUMBER 0.14  | DIAMETER RATIO 0.357<br>BEARING DN 3.00E+06 |                            |
| SPECIFIC SPEED 38.44                             | SHAFT DIAMETER 28.00                        |                            |
| SPECIFIC DIAMETER 1.99                           |   |                            |
| **************                                   | **********                                  | ****                       |
| • 02 BOOST TURBINE #                             | # 02 BOOST PU                               |                            |
| EESTOIDEN (177)                                  |   | -                          |
| EFFICIENCY (T/T) 0.877<br>EFFICIENCY (T/S) 0.812 | EFF1C1ENCY<br>HORSEPONER                    | 0.764<br>39.               |
| SPEED (RPM) 9026.                                | SPEED (RPM)                                 | 9026.                      |
| MEAN DIA (IN) 7.12<br>EFF AREA (IN2) 3.30        | S SPEED<br>HEAD (FT)                        | 3026.<br>242.              |
| U/C (ACTUAL) 8.553                               | DIA. (IN)                                   | 3.34                       |
| MAX TIP SPEED 301.<br>STAGES 1                   | TIP SPEED<br>VOL. FLOM                      | 132.<br>423.               |
| GAMMA 1.41                                       | HEAD COEF                                   | 0.450                      |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01    | FLON COEF                                   | 0.200                      |
| HORSEPONER 39.                                   |   |                            |
| EXIT MACH NUMBER 0.03<br>SPECIFIC SPEED 54.11    |   |                            |
| SPECIFIC DIAMETER 1.51                           |   |                            |
| ***********                                      | *********                                   |                            |
| * C2 TURBINE *                                   | # 02 PUMP =                                 |                            |
|  |   |                            |
| EFFICIENCY (T/T) 0.857<br>EFFICIENCY (T/S) 0.833 | EFFICIENCY<br>HORSEPOHER                    | 9.760<br>795.              |
| SPEED (RPH) \$3578.                              | SPEED (RPM)                                 | 53570.                     |
| HORSEPOMER 795.<br>MEAN DIA (IN) 3.70            | SS SPEED<br>S SPEED                         | 21532.<br>1859.            |
| C., (1,142.) 0.43                                | HEAD (FT)<br>DIA. (IN)                      | 4952.                      |
| U/C (ACTUAL) 0.531<br>MAX TIP SPEED 914.         | DIA. (IN)<br>TIP SPEED                      | 2.60                       |
| STAGES 2   | VOL. FLOM                                   | 608.<br>420.               |
| GAMMA 1.41 PRESS RATIO (T/T) 1.14                | HEAD COEF                                   | 0.431                      |
| PRESS RATIO (T/S) 1.14                           | FLOH COEF<br>DIAMETER RATIO                 | 0.156<br>0.683             |
| EXIT MACH MUMBER 0.07 SPECIFIC SPEED 43.23       | BEARING DN 1                                | . 396+06                   |
| SPECIFIC SPEED 43.23 SPECIFIC DIAMETER 1.78      | SHAFT DIAMETER                              | 26.00                      |
|  |   |                            |

# TABLE 18. -- SPLIT-EXPANDER ENGINE - 50,000 LBF THRUST (COPPER TUBE CHAMBER)

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1510.7 |
|------------------------|--------|
| VAC ENGINE THRUST      | 50000. |
| TOTAL ENGINE FLON RATE | 104.17 |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 16.18  |
| NOZZLE AREA RATIO      | 1008.0 |
| NOZZLE EXIT DIAMETER   | 143.52 |
| FIGURE MIXTURE RATIO   | 6.00   |
| FTA CH                 | 0.993  |
| CHAMBER COOLANT DP     | 487.   |
|                        | 800.   |
|                        | 22180. |
| CHAMBER COOLANT DT     |        |

|                         |                  |              | D17100F = |                  |              |
|-------------------------|------------------|--------------|-----------|------------------|--------------|
|                         |                  | SYSTEM CON   | FLON      | ENTHALPY         | DENSITY      |
| STATION                 | PRESS            |              | 14.90     | -107.5           | 4.37         |
| B.P. INLET              | 18.6             | 37.4<br>38.5 | 14.90     | -103.0           | 4.39         |
| B.P. EXIT               | 101.0            | 38.5         | 14.90     | -103.0           | 4.39         |
| PUMP INLET              | 101.0            | 61.4         | 14.90     | 6.4              | 4.54         |
| IST STAGE EXIT          |                  | 61.7         | 7.45      | 6.4              | 4.52         |
| JBV INLET               | 1999.8           | 64.5         | 7.45      | 6.4              | 4.32         |
| JBV EXIT                | 1699.9           | 73.9         | 7.45      | 67.6             | 4.60         |
| 2ND STAGE EXIT          | 3125.1<br>4227.8 | 86.1         | 7.45      | 128.5            | 4.67         |
| PUMP EXIT COOLANT INLET | 4185.5           | 86.5         | 7.45      | 128.5            | 4.65         |
| COOLANT EXIT            | 3698.9           | 886.6        | 7.45      | 3106.4           | 0.71         |
| TBV INLET               | 3662.0           | 886.9        | 0.37      | 3106.4           | 0.70         |
| TBV EXIT                | 1780.3           | 899.3        | 0.37      | 3106.4           | 0.35         |
| D2 TRB INLET            | 3662.0           | 886.9        | 7.08      | 3106.4           | 0.70         |
| OZ TRB EXIT             | 3201.7           | 862.1        | 7.08      | 3008.4           | 0.64         |
| H2 TRB INLET            | 3201.7           | 862.1        | 7.08      | 3008.4           | 0.64         |
| H2 TRB EXIT             | 1896.7           | 769.2        | 7.08      | 2649.7           | 0.44         |
| H2 TRB DIFFUSER         | 1871.9           | 769.4        | 7.08      | 2649.7           | 0.43         |
| HZ BST TRB IN           | 1853.2           | 769.4        | 7.08      | 2649.7           | 0.43         |
| H2 BST TRB OUT          | 1827.1           | 766.9        | 7.08      | 2640.1           | 0.42         |
| H2 BST TRB DIFF         | 1822.1           | 767.0        | 7.08      | 2640.1           | 0.42         |
| 02 BST TRB IN           | 1803.9           | 767.1        | 7.08      | 2640.1           | 0.42         |
| 02 BST TRB OUT          | 1790.1           | 765.7        | 7.08      | 2635.0           | 0.42         |
| 02 BST TRB DIFF         | 1789.3           | 765.7        | 7.08      | 2635.0           | 0.42         |
| HZ TANK PRESS           | 18.6             | 783.2        | 0.0153    | 2658.6           | 0.0045       |
| GOX HEAT EXCH IN        | 1780.3           | 772.4        | 7.43      | 2658.6           | 0.41         |
| GOX HEAT EXCH OUT       | 1771.4           | 771.7        | 7.43      | 2655.8           | 0.41         |
| MIXER HOT IN            | 1771.4           | 771.7        | 7.43      | 2655.8           | 0.41         |
| MIXER COLD IN           | 1699.9           | 64.5         | 7.45      | 6.4              | 4.32         |
| MIXER OUT               | 1682.8           | 405.4        | 14.88     | 1329.7           | 0.72<br>0.72 |
| FSOV INLET              | 1682.8           | 405.4        | 14.88     | 1329.7           | 0.72         |
| FSOV EXIT               | 1640.8           | 405.6        | 14.88     | 1329.7           | 0.70         |
| CHAMBER INJ             | 1624.3           | 405.6        | 14.88     | 1329.7           | 0.70         |
| CHAMBER                 | 1510.7           |              |           |                  |              |
|                         |                  |              |           | _                |              |
|                         |                  | GEN SYSTEM   |           |                  | DENSITY      |
| STATION                 | PRESS            | TEMP         | FLOH      | ENTHALPY<br>61.1 | 71.17        |
| B.P. INLET              | 16.0             | 162.7        | 89.4      | 61.5             | 71.20        |
| B.P. EXIT               | 135.6            | 163.2        | 89.4      | 61.5             | 71.20        |
| PUMP INLET              | 135.6            | 163.2        | 89.4      | 69.2             | 71.75        |
| PUMP EXIT               | 2446.6           | 173.3        | 89.4      | 204.7            | 0.12         |
| DZ TANK PRESS           | 16.0             | 400.0        | 0.151     | 69.2             | 71.71        |
| OCV INLET               | 2422.1           | 173.4        | 89.3      | 69.2             | 70.58        |
| OCV EXIT                | 1695.5           | 176.2        | 89.3      | 69.2             | 70.53        |
| CHAMBER INJ             | 1661.7           | 176.3        | 89.3      | 87.4             | 10.55        |
| CHAMBER                 | 1510.7           |              |           |                  |              |
|                         |                  |              |           |                  |              |
|                         |                  | # VALVE DA   |           | P. DVD400        |              |
| VALVE                   | DELTA P          |              | FLOW      | % BYPASS         |              |
| JBV                     | 300.             |              | 7.45      | 50.00<br>5.00    |              |
| TBV                     | 1882.            |              | 0.37      | 5.40             |              |
| FSOV                    | 42.              |              | 14.88     |                  |              |
| ocv                     | 727.             | 0.59         | 89.29     |                  |              |
|                         |                  |              | - · · ·   |                  |              |
|                         |                  | * INJECTOR   |           | VELOCITY         |              |
| INJECTOR                | DELTA P          |              | FLOM      | 1142.70          |              |
| FUEL                    | 114.             |              | 14.88     | 140.86           |              |
| LOX                     | 168.             | 1.29         | 89.29     | 140.06           |              |

TABLE 18. — SPLIT-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| ■ TURBO  | DMACHINERY PERFORMANCE DATA =   |  |  |  |  |  |
|--|---|--|--|--|--|--|
| •••••  | *******************   |  |  |  |  |  |
| *************  |   |  |  |  |  |  |
| # H2 BOOST TURBINE   | * H2 BOOST PUMP *   |  |  |  |  |  |
| ************   |   |  |  |  |  |  |
| EEE161000 1777 A   | •••   |  |  |  |  |  |
| EFFICIENCY (T/T) 0.8<br>EFFICIENCY (T/S) 0.7                 | 0.703   |  |  |  |  |  |
| SPEED (RPM) 2925   | 711 HORSEPOHER 96.<br>59. SPEED (RPH) 29259.  |  |  |  |  |  |
| MEAN DIA (IN) 1  | .00 S SPEED 3044.   |  |  |  |  |  |
| EFF AREA (1N2) 3.  |   |  |  |  |  |  |
|  | 555 DIA. (IN) 3.44  |  |  |  |  |  |
|  | 14. TIP SPEED 440. 1 VOL. FLON 1523.  |  |  |  |  |  |
| GAPHA 1.   | 40 HEAD COFF 0.458  |  |  |  |  |  |
| PRESS RATIO (T/T) 1.   | 81 FLON COEF 0.201  |  |  |  |  |  |
| PRESS RATIO (T/S) ). HORSEPOWER 9                            | 92<br>96.   |  |  |  |  |  |
| EXIT HACH MUMBER 0.  |   |  |  |  |  |  |
| SPECIFIC SPEED 112.  | 51  |  |  |  |  |  |
| SPECIFIC DIAMETER 0.   | 77  |  |  |  |  |  |
|  |   |  |  |  |  |  |
| ********   |   |  |  |  |  |  |
| * H2 TURBINE #   | # H2 PUMP #   |  |  |  |  |  |
| **********   | D#22454018  |  |  |  |  |  |
|  | STAGE ONE STAGE THO STAGE THREE   |  |  |  |  |  |
| EFFICIENCY (T/T) 0.8   | 69 EFFICIENCY 0.726 0.723 8.722   |  |  |  |  |  |
| FFFICIENCY (T/S) 0.8   | 43 HORSEPOHER 2304, 645, 642,   |  |  |  |  |  |
| SPEED (RPM) 10000  | B. SPEED (RPM) 100000 100000 100000   |  |  |  |  |  |
| HORSEPONER 359<br>HEAN DIA. (IN) 3.                          | 1. SS SPEED 12793.  |  |  |  |  |  |
| HEAN DIA. (IN) 3.<br>EFF AREA (IN2) 0.                       | 1. SS SPEED 12793.<br>47 S SPEED 900. 1065. 1063.<br>47 HEAD (FT) 61758. 34459. 34238.<br>34 DIA. (IN) 4.44 3.39 3.39 |  |  |  |  |  |
| U/C (ACTUAL) 0.5   | 34 DIA. (IN) 4.44 3.39 3.39   |  |  |  |  |  |
| MAX TIP SPEED 170  | 8. TIP SPEED 1939. 1479. 1479.  |  |  |  |  |  |
| 21 W/YC 2  | 2 VOL. FLON 1472. 726. 716.   |  |  |  |  |  |
| PRESS RATIO (T/T) 1.0  |   |  |  |  |  |  |
|  |   |  |  |  |  |  |
| PRESS RATIO (T/S) 1. EXIT MACH MUMBER 0.1 SPECIFIC SPEED 46. | 15 BEARING DN 3.00E+06  |  |  |  |  |  |
| SPECIFIC SPEED 46.1  | 16 SHAFT DIAMETER 30.00   |  |  |  |  |  |
| SPECIFIC DIAMETER 1.   | ••  |  |  |  |  |  |
|  |   |  |  |  |  |  |
| ***************  |   |  |  |  |  |  |
| * 02 BOOST TURBINE   |   |  |  |  |  |  |
|  | •   |  |  |  |  |  |
| EFFICIENCY (T/T) 0.88  | EFFICIENCY 0.764  |  |  |  |  |  |
| EFFICIENCY (T/S) 0.81  |   |  |  |  |  |  |
| SPEED (RPM) 78)7<br>MEAN DIA (IN) 8.2                        |   |  |  |  |  |  |
| EFF AREA (IN2) 4.3   | 22 \$ SPEED 3026.<br>80 HEAD (FT) 242.  |  |  |  |  |  |
| U/C (ACTUAL) 0.55  |   |  |  |  |  |  |
| HAX TIP SPEED 301  | •   |  |  |  |  |  |
| STAGES GAPPA 1.6   | 1 VOL. FLON 564,<br>10 HEAD_COEF 9,450  |  |  |  |  |  |
| PRESS RATIO (T/T) 1.0  |   |  |  |  |  |  |
| PRESS RATIO (T/S) 1.0  | 01  |  |  |  |  |  |
| HORSEPONER 51  | _   |  |  |  |  |  |
| EXIT MACH HUMBER 0.0<br>SPECIFIC SPEED 53.7                  | 13<br>10  |  |  |  |  |  |
| SPECIFIC DIAMETER 1.5  |   |  |  |  |  |  |
|  |   |  |  |  |  |  |
|  |   |  |  |  |  |  |
|  |   |  |  |  |  |  |
| * 02 TURBINE *   | #####################################   |  |  |  |  |  |
|  | * ()2 P()+P n   |  |  |  |  |  |
| = 02 TURBINE =   | * 02 PUMP **  |  |  |  |  |  |
| # 02 TURBINE #   | # 02 PUMP # ################################  |  |  |  |  |  |
| = 02 TURBINE =   | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE *   | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE **  EFFICIENCY (T/T)                            | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE *   | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE **  EFFICIENCY (T/T)                            | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE *   | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE * * * * * * * * * * * * * * * * * * *           | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE *   | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE * * * * * * * * * * * * * * * * * * *           | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE * * * * * * * * * * * * * * * * * * *           | # 02 PUMP # ################################  |  |  |  |  |  |
| # 02 TURBINE * * * * * * * * * * * * * * * * * * *           | # 02 PUMP # ################################  |  |  |  |  |  |

TABLE 19. — DUAL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER)

|     | ENGI | ΝE | PE      | υFO | RM    | HC  | E P | A.R | AM | E١ | EF    | S |    |    |  |
|-----|------|----|---------|-----|-------|-----|-----|-----|----|----|-------|---|----|----|--|
| ••• |      |    | • • • • | ••• | • * 1 | ••• | *** | ••  | •• | •  | • • • | • | •• | •• |  |

| CHAMBER PRESSURE            | 1371.2 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 7500.  |
| TOTAL ENGINE FLON RATE      | 15.63  |
| DEL. VAC. ISP               | 479.9  |
| THROAT AREA                 | 2.67   |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 58.32  |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C.                      | 0.993  |
| CHAMBER COOLANT DP          | 429.   |
| CHAMBER COOLANT DT          | 490.   |
| NOZZLE COOLANT DP           | 186.   |
| NOZZLE COOLANT DT           | 564.   |
| CHAMBER Q (HYDROGEN COOLED) | 4196.  |
| NOZZLE Q (OXYGEN COOLED)    | 2574.  |
|                             |        |

|  | ******** |                         |  |  |               |
|--|----------|-------------------------|--|--|---------------|
|  | FUEL     | SYSTEM CO               | ADITIONS .   |  |               |
| STATION B.P. INLET B.P. EXIT PUMP INLET IST STAGE EXIT PUMP EXIT COOLANT INLET COOLANT EXIT TBY INLET TBY EXIT | PRESS    | TEMP                    | FLON   | ENTHALPY   | DENSITY       |
| B.P. INLET   | 18.6     | 37.4                    | 2.24   | -107.5   | 4.37          |
| B.P. EXIT  | 100.8    | 38.5                    | 2.24   | -103.0   | 4.39          |
| PUMP INLET   | 100.8    | 38.5                    | 2.24   | -103.0   | 4.39          |
| IST STAGE EXIT   | 1703.5   | 64.3                    | 2.24   | 5.9  | 4.33          |
| PUMP EXIT  | 3256.5   | 88.4                    | 2.24   | 111.2  | 4.32          |
| COOLANT INLET  | 3223.9   | 88.7                    | 2.24   | 111.2  | 4.31          |
| COOLANT EXIT   | 2794.6   | 578.3                   | 2.24   | 1988.1   | 0.82          |
| TBV INLET  | 2766.7   | 578.5                   | 0.11   | 1988.1   | 0.81          |
| TBV INLE! TBV EXIT H2 TRB INLET H2 TRB EXIT H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT H2 BST TRB DIFF       | 1527.4   | 584.5                   | 0.11   | 1988.1   | 0.46<br>0.81  |
| H2 TRB INLET   | 2766.7   | 578.5                   | 2.12<br>2.12<br>2.12<br>2.12<br>2.12<br>2.12<br>2.12<br>2.23 | 1988.1   | 0.54          |
| H2 TRB EXIT  | 1607.8   | 522.2                   | 2.12   | 1762.7   | 0.53          |
| H2 TRB DIFFUSER  | 1578.5   | 522.3                   | 2.12   | 1762.7<br>1762.7   | 0.53          |
| H2 BST TRB IN  | 1562.8   | 522.3                   | 2.12   | 1757.9   | 0.52          |
| H2 BST TRB OUT   | 1542.2   | 521.2                   | 2.12   |  | 0.52          |
| H2 BST TRB DIFF  | 1527.4   | 521.2                   | 2.12   | 1757.9<br>1769.4   | 0.0066        |
| H2 TANK PRESS  | 18.6     | 530.5                   | 0.0034   | 1767.4   | 0.51          |
| FSOV INLET   | 1527.4   | 524.4                   | 2.23   | 1767.4   | 0.50          |
| FSOV EXIT  | 1489.2   | 524.5                   | 2.23   | 1769.4<br>1769.4<br>1769.4   | 0.50          |
| CHAMBER INJ  | 1474.3   | 524.0                   | 2.23   | 1/4/.4   |               |
| H2 BST THE DIFF H2 TANK PRESS FSOV INLET FSOV EXIT CHAMBER INJ CHAMBER   | 1371.2   |                         |  |  |               |
|  |          |                         | CONDITIONS   | s •  |               |
| STATION  | PRESS    | TEMP                    | FLON   | ENTHALPY<br>61.1<br>61.5<br>61.5<br>79.1<br>79.1<br>271.0<br>271.0 | DENSITY       |
| B.P. INLET   | 16.0     | 162.7                   | 13.4   | 61.1   | 71.17         |
| B.P. EXIT  | 135.6    | 163.2                   | 13.4   | 61.5   | 71.20         |
| PUMP INLET   | 135.6    | 163.2                   | 13.4   | 61.5   | 71.20         |
| PUMP INLET PUMP EXIT   | 4864.9   | 188.4                   | 13.4   | 79.1   | 71.57         |
| COOLANT INLET  | 4816.2   | 188.6                   | 13.4   | 79.1   | 71.50         |
| COOLANT EXIT   | 4630.0   | 752.7                   | 13.4   | 271.0<br>271.0   | 16.91         |
| OTBV INLET   | 4630.0   | 752.7                   | 0.6  | 271.0  |               |
| OTBV IMLE: OTBV EXIT O2 TRB IMLET O2 TRB EXIT O2 TRB DIFFUSER O2 BST TRB IN O2 BST TRB OUT                     | 2313.4   | 735.0                   | 0.6  | 271.0  | 9.19          |
| OZ TRB INLET   | 4630.0   | 752.7                   | 11.5   | 271.0  | 16.91         |
| OZ TRB EXIT  | 2516.1   | 456.8                   | 11.5   | 250.4  | 11.38         |
| 02 TRB DIFFUSER  | 2313.4   | 653.9                   | 11.5   | 250.4  | 10.54         |
| OZ BST TRB IN  | 4630.0   | 752.7                   | 1.3  | 271.0  | 16.91         |
| OZ BST TRB OUT   | 4598.2   | 737.4                   | 1.3  | 267.0<br>267.0   | 17.22         |
| 02 BST TRB DIFF  | 4596.8   | 737.4                   |  |  | 17.21         |
| OBTV INLET   | 4596.8   | 737.4                   | 1.3  | 267.0  | 17.21<br>9.43 |
| OBTV EXIT  | 2313.4   | 718.8                   | 1.3  | 267.0  | 10.36         |
| MIXER  | 2313.4   | 663.9                   | 13.4   | 253.0  | 0.08          |
| DZ TANK PRESS  | 16.0     | 663.9<br>619.8<br>662.3 | 1.3<br>13.4<br>0.015   | 253.0<br>253.0   | 9.88          |
| DCV INLET  | 2197.7   | 662.3                   |  | 253.0  | 7.09          |
| OCV EXIT   | 1538.4   | 652.0                   | 13.4   | 253.0  | 7.02          |
| CHAMBER INJ  | 1523.0   | 651.7                   | 13.4   | 233.0  | ,             |
| O2 BST TRB OUT O2 BST TRB DIFF OBTV INLET OBTV EXIT MIXER O2 TANK PRESS OCV INLET OCV EXIT CHAMBER INJ CHAMBER | 1371.2   |                         |  |  |               |
|  |          | . VALVE DA              | TA P   |  |               |
|  |          |                         |  |  |               |
| VALVE  | DELTA P  | AREA                    | FLON   | * BYPASS   |               |
| OTBV   | 2317.    |                         |  | 5.00   |               |
| TBV  | 1239.    | 0.01                    |  | 5.00   |               |
| FSOV   | 38.      |                         | 2.23   |  |               |
| OBTV   | 2283.    |                         |  |  |               |
| OCV  | 659.     | 0.25                    | 13.39  |  |               |
|  |          | INJECTOR                | DATA .   |  |               |
| IN IECTOR  | DELTA    | ADFA                    | FLOH   | VELOCITY   |               |
| INJECTOR   | 103.     | 0.47                    | 2.23   | 1278.14  |               |
| FUEL   | 163.     | 0.51                    | 2.23<br>13.39  | 426.51   |               |
| LOX  | 134 1    | U. •1                   | ,  |  |               |

TABLE 19. — DUAL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|                            |               |                | HINERY PERFORMANCE  |                  |                |  |  |
|----------------------------|---------------|----------------|---------------------|------------------|----------------|--|--|
|                            |               | *******        | *************       |                  |                |  |  |
|                            |               | RBINE *        |                     |                  |                |  |  |
|                            |               |                |                     | H2 B00ST         |                |  |  |
| EFF ICIENCY                |               |                |                     | CIENCY           |                |  |  |
| EFF1C1ENCY                 | (T/S)         |                | 2                   | EPOMER           | 0.765<br>14.   |  |  |
|                            |               | 75466.         |                     | D (RPH)          |                |  |  |
| MEAN DIA                   | (IN)          | 0.82           | S SP                |                  | 3045.          |  |  |
| EFF AREA                   | [ IN2 )       | 0.94           | HEAD                |                  |                |  |  |
| U/C (A                     | CTUAL )       | 0.553          | DIA.                | (IN)             |                |  |  |
| MAX TIP SPE                | ED            | 394.           | TIP :               | SPEED            | 439.           |  |  |
| STAGES                     |               | 1              |                     | FLOH             | 229.           |  |  |
| GAMMA                      |               | 1.39           |                     | COEF             | 0.450          |  |  |
| PRESS RATIO                |               |                | FLOH                | COEF             | 0.201          |  |  |
| PRESS RATIO                | (1/5)         |                |                     |                  |                |  |  |
| EXIT MACH N                | LIMRED        | 14.<br>0.11    |                     |                  |                |  |  |
| SPECIFIC SP                |               |                |                     |                  |                |  |  |
| SPECIFIC DI                |               |                |                     |                  |                |  |  |
|                            |               |                |                     |                  |                |  |  |
| *****                      | *****         | •              |                     | *******          |                |  |  |
| ■ H2 TU                    |               |                |                     | # H2 PUMF        |                |  |  |
| ******                     | *****         | •              |                     | *******          |                |  |  |
|                            |               |                |                     | STAGE ONE        |                |  |  |
|                            |               | _              |                     | ********         |                |  |  |
| EFFICIENCY                 |               |                |                     | 0.627            |                |  |  |
| EFFICIENCY<br>SPEED        |               |                |                     | 345.             |                |  |  |
| SPEED<br>HORSEPOHER        |               | 677            |                     | 187500.          | 187500.        |  |  |
|                            |               |                | SS SPEED<br>S SPEED | 9304.            |                |  |  |
| EFF AREA                   | (IN)<br>(IN2) | 0.13           |                     | 816.<br>53103.   |                |  |  |
|                            |               |                |                     | 2.22             |                |  |  |
| MAX TIP SPEI               | ED            | 0.513<br>1800. | TIP SPEED           | 1818.            |                |  |  |
| STAGES                     |               | 1              | VOL. FLOW           | 232.             |                |  |  |
| GAMMA                      |               | 1.39           | HEAD COEF           | 0.517            | 0.503          |  |  |
| PRESS RATIO                |               |                | FLOM COEF           | 0.098            |                |  |  |
| PRESS RATIO                |               |                | DIAMETER RATIO      | 0.332            |                |  |  |
| EXIT MACH NI               |               | 0.16           |                     | 3.00E • 06       |                |  |  |
| SPECIFIC SPE               |               | 34.00          | SHAFT D!AMETER      | 16.00            |                |  |  |
| SPECIFIC DIA               | METER         | 2.10           |                     |                  |                |  |  |
| *******                    |               |                |                     | *******          |                |  |  |
| • C2 BOO                   |               |                |                     | 02 BOOST P       |                |  |  |
| ******                     |               |                |                     | *****            |                |  |  |
| EFFICIENCY                 |               |                |                     | IENCY            | 0.764          |  |  |
| EFFICIENCY                 |               |                | HORSE               | POHER            | 8.             |  |  |
| SPEED                      | (RPM)         |                | SPEED               | (RPH)            | 20189.         |  |  |
| MEAN DIA<br>EFF AREA       | (IN)          | 2.83           | S SPE               |                  | 3026.          |  |  |
|                            |               |                |                     | (FT)             | 242.           |  |  |
| MAX TIP SPEE               |               | 0.553          | DIA.                | (IN)             | 1.49           |  |  |
| STAGES                     |               | 263.<br>1      | TIP SI<br>VOL. I    |                  | 132.           |  |  |
| GAMMA                      |               | 1.60           | HEAD (              |                  | 85.            |  |  |
|                            | (T/T)         | 1.01           | FLON (              |                  | 0.450<br>0.200 |  |  |
| PRESS RATIO<br>PRESS RATIO | (T/\$)        | 1.01           |                     |                  |                |  |  |
| HORSEPOHER                 |               | 8.             |                     |                  |                |  |  |
| EXIT MACH NU               |               | 0.02           |                     |                  |                |  |  |
| SPECIFIC SPE               |               | 41.74          |                     |                  |                |  |  |
| SPECIFIC DIA               | METER         | 1.85           |                     |                  |                |  |  |
| ******                     |               |                |                     |                  | _              |  |  |
| • 02 TUR                   |               |                |                     | 02 PUMP          |                |  |  |
| *******                    |               |                |                     | . 02 PUMP .      |                |  |  |
| EFFICIENCY                 | (T/T)         | 0.811          | EFF ICI             |                  | 0.693          |  |  |
| EFF ICIENCY                |               |                |                     | OHER             | 335.           |  |  |
| SPEED                      | (RPH)         | 156345.        |                     |                  | 156345.        |  |  |
| HORSEPOHER                 |               | 335.           | SS SPE              |                  | 28091.         |  |  |
|                            | (IN)          | 0.82           | S SPEE              |                  | 1488.          |  |  |
|                            | (1N2)         | 0.12           | HEAD                |                  | 9514.          |  |  |
|                            |               | 0.553          |                     | (IN)             | 1.22           |  |  |
| MAX TIP SPEET              | D             | 648.           | TIP SP              |                  | 835.           |  |  |
| STAGES                     |               | 1              | VOL. F              |                  | 84.            |  |  |
| GAMMA<br>PRESS RATIO       | (T/T)         | 1.60           | HEAD C              | -                | 0.439          |  |  |
| PRESS RATIO                |               | 1.84<br>2.06   | FLOH C              |                  | 0.138          |  |  |
| EXIT MACH NU               |               | 0.33           |                     | ER RATIO<br>G DN | 0.669          |  |  |
| SPECIFIC SPE               | E D           | 85.30          |                     | G DN<br>DIAMETER |                |  |  |
| SPECIFIC DIA               |               | 0.96           | S                   |                  |                |  |  |
|                            |               |                |                     |                  |                |  |  |

TABLE 20. — DUAL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER)

| CHAMBER PRESSURE            | 1218.5 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 15000. |
| TOTAL ENGINE FLOW RATE      | 31.26  |
| DEL. VAC. ISP               | 479.9  |
| THROAT AREA                 | 6.01   |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 87.46  |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C.                      | 0.993  |
| CHAMBER COOLANT DP          | 399.   |
| CHAMBER COOLANT DT          | 394.   |
| NOZZLE COOLANT DP           | 212.   |
| NOZZLE COOLANT DT           | 439.   |
| CHAMBER Q (HYDROGEN COOLED) | 6797.  |
| NOZZLE Q (OXYGEN COOLED)    | 4210.  |

#### ENGINE STATION CONDITIONS

|                 | ENGINE  | STATION    | CONDITIONS |          |         |
|-----------------|---------|------------|------------|----------|---------|
|                 | ******* | ********   |            |          |         |
|                 | • FUFI  | SYSTEM CO  | * ZMOITION |          |         |
| STATION         | PRESS   | TEMP       | FLOH       | ENTHALPY | DENSITY |
| B.P. INLET      | 18.6    | 37.4       | 4.47       | -107.5   | 4.37    |
| B.P. EXIT       | 100.8   | 38.5       | 4.47       | -103.0   | 4.39    |
| PUMP INLET      | 100.8   | 38.5       | 4.47       | -103.0   | 4.39    |
| 1ST STAGE EXIT  | 1459.8  | 56.9       | 4.47       | -20.2    | 4.44    |
| PUMP EXIT       | 2814.1  | 74.6       | 4.47       | 61.5     | 4.49    |
| COOLANT INLET   | 2786.0  | 74.8       | 4.47       | 61.5     | 4.47    |
| COOLANT EXIT    | 2386.6  | 469.3      | 4.47       | 1580.9   | 0.84    |
| TBV INLET       | 2362.7  | 469.4      | 0.22       | 1580.9   | 0.85    |
| TBV EXIT        | 1357.6  | 473.2      | 0.22       | 1580.9   | 0.51    |
| H2 TRB INLET    | 2362.7  | 469.4      | 4.25       | 1580.9   | 0.85    |
| H2 TRB EXIT     | 1440.9  | 426.3      | 4.25       | 1407.8   | 0.59    |
| H2 TRB DIFFUSER | 1407.1  | 426.4      | 4.25       | 1407.B   | 0.58    |
| H2 BST TRB IN   | 1393.0  | 426.4      | 4.25       | 1407.8   | 0.58    |
| H2 BST TRB OUT  | 1371.8  | 425.2      | 4.25       | 1403.0   | 0.57    |
| H2 BST TRB DIFF | 1357.6  | 425.2      | 4.25       | 1403.0   | 0.56    |
| HZ TANK PRESS   | 18.6    | 431.1      | 0.0083     | 1411.9   | 0.0081  |
| FSOV INLET      | 1357.6  | 427.6      | 4.47       | 1411.9   | 0.56    |
| FSOV EXIT       | 1323.7  | 427.7      | 4.47       | 1411.9   | 0.55    |
| CHAMBER INJ     | 1310.5  | 427.B      | 4.47       | 1411.9   | 0.54    |
| CHAMBER         | 1218.5  |            |            |          |         |
|                 | # OXY   | GEN SYSTER | CONDITION  | s •      |         |
| STATION         | PRESS   | TEMP       | FLOH       | ENTHALPY | DENSITY |
| B.P. INLET      | 16.0    | 162.7      | 26.8       | 61.1     | 71.17   |
| B.P. EXIT       | 135.6   | 163.2      | 26.8       | 61.5     | 71.20   |
| PUMP INLET      | 135.6   | 163.2      | 26.8       | 61.5     | 71.20   |
| PUMP EXIT       | 5031.7  | 187.5      | 26.8       | 79.0     | 71.84   |
| COOLANT INLET   | 4981.3  | 187.7      | 26.8       | 79.0     | 71.76   |
| COOLANT EXIT    | 4769.4  | 626.4      | 26.B       | 235.9    | 21.59   |
| OTBY INLET      | 4769.4  | 626.4      | 1.2        | 235.9    | 21.59   |
|                 |         |            |            |          |         |

| STATION         | PRESS  | TEMP  | FLOH  | ENTHALPY | DENSITY |
|-----------------|--------|-------|-------|----------|---------|
| B.P. INLET      | 16.0   | 162.7 | 26.8  | 61.1     | 71.17   |
| B.P. EXIT       | 135.6  | 163.2 | 26.8  | 61.5     | 71.20   |
| PUMP INLET      | 135.6  | 163.2 | 26.8  | 61.5     | 71.20   |
| PUMP EXIT       | 5031.7 | 187.5 | 26.8  | 79.0     | 71.84   |
| COOLANT INLET   | 4981.3 | 187.7 | 26.8  | 79.0     | 71.76   |
| COOLANT EXIT    | 4769.4 | 626.4 | 26.B  | 235.9    | 21.59   |
|                 | 4769.4 | 626.4 | 1.2   | 235.9    | 21.59   |
| OTBV INLET      | 2056.5 | 594.0 | 1.2   | 235.9    | 10.60   |
| OTBV EXIT       | 4769.4 | 626.4 | 22.9  | 235.9    | 21.59   |
| 02 TRB INLET    |        | 523.0 | 22.9  | 215.4    | 13.93   |
| 02 TRB EXIT     | 2268.6 |       |       | 215.4    | 12.77   |
| O2 TRB DIFFUSER | 2056.5 | 518.3 | 22.9  |          |         |
| O2 BST TRB IN   | 4769.4 | 626.4 | 2.7   | 235.9    | 21.59   |
| OZ BST TRB OUT  | 4730.5 | 611.B | 2.7   | 231.9    | 22.07   |
| OZ BST TRB DIFF | 4728.9 | 611.8 | 2.7   | 231.9    | 22.07   |
| OBTY INLET      | 4728.9 | 611.8 | 2.7   | 231.9    | 22.07   |
| OBTV EXIT       | 2056.5 | 578.5 | 2.7   | 231.9    | 10.96   |
| MIXER           | 2056.5 | 527.4 | 26.8  | 218.0    | 12.45   |
| 02 TANK PRESS   | 16.0   | 460.5 | 0.039 | 218.0    | 0.10    |
| OCV INLET       | 1953.6 | 525.1 | 26.8  | 218.0    | 11.89   |
|                 | 1367.5 | 510.0 | 26.8  | 218.0    | 8.55    |
| OCV EXIT        |        |       |       | 218.0    | 8.47    |
| CHAMBER INJ     | 1353.9 | 509.6 | 26.8  | 210.0    | 0.41    |
| CHAMBER         | 1218.5 |       |       |          |         |

#### . VALVE DATA .

| VALVE | DELTA P | AREA | FLOH  | % BYPASS |
|-------|---------|------|-------|----------|
| OTBV  | 2713.   | 0.01 | 1.21  | 5.00     |
| TBV   | 1005.   | 0.01 | 0.22  | 5.00     |
| FSOV  | 34.     | 1.51 | 4.47  |          |
| OBTV  | 2672.   | 0.02 | 2.68  |          |
| ncv   | 586.    | 0.48 | 26.79 |          |

#### \* INJECTOR DATA \*

| INJECTOR | DELTA P | AREA | FLOW  | VELOC1TY |
|----------|---------|------|-------|----------|
| FUEL     | 92.     | 0.96 | 4.47  | 1159.15  |
| LOX      | 135.    | 1.18 | 26.79 | 366.80   |

TABLE 20. — DUAL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|   |              | ******        |                        |                 |                 |
|---|--------------|---------------|------------------------|-----------------|-----------------|
|   |              |               | CHINERY PERFORMANCE I  |                 |                 |
|   |              |               | ***************        |                 |                 |
| • H2 BOOS   |              |               |                        | H2 BOOST F      |                 |
| ******  |              |               |                        | 72 BUUS! /      |                 |
| EFFICIENCY (  | T/T)         | 0.740         |                        | IENCY           | 0.765           |
| EFFICIENCY (  | T/S1         | 0.391         |                        | POHER           | 29.             |
|   | RPM)         |               | SPEET                  | (RPH)           | 53342.          |
|   |              | 1.16          | \$ \$25                |                 | 3045.           |
|   | IN2)         |               | HEAD                   |                 | 2700.           |
| MAX TIP SPEED                                       | UALI         | 0.551<br>390. | DIA.                   | (IN)<br>SPEED   | 1.89<br>439.    |
| STAGES  |              | 1             |                        | FLOW            | 457.            |
| GAJTHA  |              | 1.40          | HEAD                   |                 | 0.450           |
| PRESS RATIO   | T/T)         |               | FLOH                   | COEF            | 0.201           |
| PRESS RATIO (                                       | T/S)         |               |                        |                 |                 |
| HORSEPOHER  |              | 29.           |                        |                 |                 |
| EXIT MACH NUM<br>SPECIFIC SPEE                      |              | 0.12          |                        |                 |                 |
| SPECIFIC DIAM                                       |              |               |                        |                 |                 |
| Sectific plan                                       | C.CA         | 0.52          |                        |                 |                 |
| ******  | ****         |               |                        |                 |                 |
| # H2 TURB   | INE .        |               |                        | # H2 PUMP       | • •             |
|   | # # # # #    |               |                        | ******          |                 |
|   |              |               |                        | STAGE ONE       |                 |
| EFFICIENCY (  | T / T \      | 0.010         | EFFICIENCY             | *******         |                 |
| EFFICIENCY (  |              |               |                        | 0.486           | 0.687           |
| SPEED (   |              |               |                        | 524.<br>136363. | 517.<br>136363. |
| HORSEPOHER  |              | 1041.         | SS SPEED               | 9574.           |                 |
| MEAN DIA.   | (IN)         |               | S SPEED                | 951.            |                 |
| EFF AREA (  | I N2 )       | 0.28          | HEAD (FT)              | 44223.          | 43654.          |
| U/C (ACT  | UAL )        | 0.553         | DIA. (IN)              | 2.79            |                 |
| MAX TIP SPEED<br>STAGES                             |              | 1713.         | TIP SPEED              | 1659.           |                 |
| GANNA   |              | 1<br>1.40     | VOL. FLOM<br>HEAD COEF | 452.            | 447.            |
| PRESS RATIO (                                       | T / T / T    |               |                        | 0.517<br>0.107  | 0.511           |
| PRESS RATIO (                                       | T/S)         | 1.69          |                        |                 |                 |
| EXIT HACH NUM                                       | BER          | 0.19          | BEARING DN             | 3.00E+06        |                 |
| SPECIFIC SPEE                                       |              | 41.25         | SHAFT DIAMETER         | 22.00           |                 |
| SPECIFIC DIAM                                       | ETER         | 1.89          |                        |                 |                 |
| *******   |              | ****          |                        | *********       |                 |
| • 02 BOOS   |              |               |                        | 02 BOOST P      |                 |
| ******  |              |               |                        | ******          |                 |
| EFFICIENCY (  |              |               |                        | IENCY           | 0.764           |
| EEEICIENCA (  |              |               | HORSE                  | POHER           | 15.             |
|   | RPM)         |               |                        | (RPH)           |                 |
| MEAN DIA  | (IN)<br>IN2) | 4.01<br>0.14  | S SPE                  |                 | 3026.<br>242.   |
| U/C (ACT)   | IAL )        | 0.553         | DIA.                   | (FT)<br>(IN)    | 2.11            |
| MAX TIP SPEED                                       |              | 261.          | TIP S                  | PEED            | 132.            |
| STAGES  |              | 1             | VOL.                   | FLOH            | 169.            |
| GAPPHA  |              | 1.73          | HEAD (                 |                 | 0.450           |
| PRESS RATIO (1                                      |              | 1.01          | FLOM (                 | COEF            | 0.200           |
| HORSEPOHER  | 1/51         | 1.01          |                        |                 |                 |
| _   | BER          |               |                        |                 |                 |
| SPECIFIC SPEEL                                      | )            | 38.01         |                        |                 |                 |
| SPECIFIC DIAME                                      | TER          | 2.04          |                        |                 |                 |
|   |              |               |                        |                 |                 |
| - 02 7100   |              |               |                        |                 |                 |
| - 02 TURBI  |              |               |                        | 02 PUMP :       |                 |
|   |              | 0.830         |                        | ENCY            | 0.717           |
| EFFICIENCY (1                                       | <b>7</b> S)  | 0.722         | HORSE                  | OHER            | 667.            |
| SPEED (F  | PM) 1        |               | SPEED                  | (RPH)           | 110421.         |
| SPEED (R<br>HORSEPOHER<br>MEAN DIA (<br>FEE AREA (I |              | 667.          | SS SPE                 | ED              | 28065.          |
| MEAN DIA C  | INI          | 1.16          | 3 34 (                 |                 | 1450.           |
|   |              | 0.20          | HEAD                   | (FT)<br>(IN)    | 9811.           |
| U/C (ACTU   |              | 0.553<br>640. | DIA.<br>TIP SF         |                 | 1.73            |
| STAGES  |              | 1             | 11P SP<br>VOL. F       |                 | 834.<br>148.    |
| GAIPIA  |              | 1.73          | HEAD O                 |                 | 0.454           |
| PRESS RATIO (T                                      | /T)          | 2.10          | FLOH C                 |                 | 0.136           |
| PRESS RATIO (T                                      | /\$)         | 2.40          | DIAMET                 | ER RATIO        | 0.669           |
| EXIT MACH NUMB                                      |              | 0.35          |                        | IG DN           |                 |
| SPECIFIC SPEED                                      |              | 81.68         | SHAFT                  | DIAMETER        | 14.00           |
| SPECIFIC DIAME                                      | IEM          | 1.01          |                        |                 |                 |
|   |              |               |                        |                 |                 |

#### TABLE 21. — DUAL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER)

| ENGINE | PERFORMANCE P | ARAMETERS |
|--------|---------------|-----------|
|        |               | ********* |

| CHAMBER PRESSURE            | 1158.7 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 25000. |
| TOTAL ENGINE FLON RATE      | 52.10  |
| DEL. VAC. ISP               | 479.9  |
| THROAT AREA                 | 10.52  |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 115.76 |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C                       | 0.993  |
| CHAMBER COOLANT DP          | 335.   |
| CHAMBER COOLANT DT          | 347.   |
| NOZZLE COOLANT DP           | 233.   |
| NOZZLE COOLANT DT           | 373.   |
| CHAMBER Q (HYDROGEN COOLED) | 9968.  |
| NOZZLE Q (DXYGEN COOLED)    | 6216.  |
|                             |        |

|  |                  |                | CONDITIONS             |                  |              |
|--|------------------|----------------|------------------------|------------------|--------------|
|  |                  | *******        | *******                |                  |              |
|  |                  |                |                        |                  |              |
|  | * FUEL S         | SYSTEM CON     | DITIONS .              |                  |              |
| STATION  | PRESS            | TEI₽           |                        | ENTHALPY         | DENSITY      |
| B.P. INLET   | 18.6             | 37.4           | 7.46                   | -107.5           | 4.37         |
| B.P. EXIT  | 100.5            | 38.5           | 7.46                   | -103.0           | 4.39         |
| PUMP INLET   | 100.5            | 38.5           | 7.46                   | -103.0           | 4.39         |
| IST STAGE EXIT                                     | 1276.3           | 52.3           | 7.46                   | -37.0            | 4.50         |
| PUMP EXIT  | 2470.4           | 65.7           | 7.46                   | 29.0             | 4.59         |
| COOLANT INLET                                      | 2445.7           | 66.0           | 7.46                   | 29.0             | 4.57         |
| COOLANT EXIT                                       | 2110.5           | 413.4          | 7.46                   | 1365.6           | 0.87<br>0.86 |
| TBV INLET  | 2089.4           | 413.5          | 0.37                   | 1365.6           | 0.55         |
| TBV EXIT   | 1291.4           | 415.7          | 0.37                   | 1365.6           | 0.86         |
| H2 TRB INLET                                       | 2089.4           | 413.5          | 7.09                   | 1365.6           | 0.64         |
| H2 TRB EXIT  | 1377.3           | 379.6          | 7.09                   | 1226.6           | 0.62         |
| H2 TRB DIFFUSER                                    |                  | 379.7          | 7.09                   | 1226.6           | 0.62         |
| H2 BST TRB IN                                      | 1325.1           | 379.7          | 7.09                   | 1226.6           | 0.61         |
| H2 BST TRB OUT<br>H2 BST TRB DIFF                  | 1304.8           | 370.5          | 7.09                   | 1221.8           | 0.60         |
| H2 BST TRB DIFF                                    | 1291.4           | 378.5          | 7.07                   | 1221.8<br>1229.0 | 0.0092       |
| H2 IAM PRESS                                       | 18.6             | 382.2          | 7.09<br>0.0157<br>7.44 | 1229.0           | 0.60         |
| FSOV INLET   | 1291.4           | 380.4          | 7.44                   | 1229.0           | 0.59         |
| FSOV EXIT  | 1259.1           | 380.4          | 7.44                   | 1229.0           | 0.58         |
| CHAMBER INJ  | 1246.5           | 380.5          | 7.44                   | 1227.0           | 0.50         |
| CHAMBER  | 1158.7           |                |                        |                  |              |
|  |                  |                |                        |                  |              |
|  |                  | EN SAZIEM      | CONDITIONS             | ENTHALPY         | DENSITY      |
| STATION  | PRESS            |                | 44.7                   | 61.1             | 71.17        |
| B.P. INLET   | 16.0             | 162.7          | 44.7                   | 61.5             | 71.20        |
| B.P. EXIT  | 135.6            | 163.2          | 44.7                   | 61.5             | 71.20        |
| PUMP INLET   | 135.6            | 163.2          | 44.7                   | 77.5             | 71.98        |
| PUMP EXIT  | 4749.6           | 184.9          | 44.7                   | 77.5             | 71.91        |
| COOLANT INLET                                      | 4782.1           | 185.1<br>558.1 | 44.7                   | 216.5            | 23.78        |
| COOLANT EXIT                                       | 4469.5<br>4469.5 | 558.1          | 2.0                    | 216.5            | 23.78        |
| OTBV INLET   |                  | 519.9          | 2.0                    | 216.5            | 12.07        |
| OTBY EXIT  | 1955.0           | 558.1          | 38.2                   | 216.5            | 23.78        |
| 02 TRB INLET                                       | 4469.5           | 460.9          | 38.2                   | 197.7            | 16.13        |
| O2 TRB EXIT  | 2356.0<br>1955.0 | 455.3          | 38.2                   | 197.7            | 14.84        |
| 02 TRB DIFFUSER                                    |                  | 558.1          | 4.5                    | 216.5            | 23.78        |
| O2 BST TRB IN<br>O2 BST TRB OUT<br>O2 BST TRB DIFF | 4487.3           | 544.5          | 4.5                    | 212.4            | 24.41        |
| 02 851 IKB 001                                     | 4430.0           | 544.5          | 4.5                    | 212.4            | 24.41        |
| OBTV INLET   | 4429.0           | 544.5          | 4.5                    | 212.4            | 24.41        |
| OBTV EXIT  | 1955.0           | 505.5          | 4.5                    | 212.4            | 12.57        |
| MIXER  |                  | 462.5          | 44.7                   | 200.0            | 14.46        |
| MIXER 02 TANK PRESS 0CV INLET 0CV EXIT             | 16.0             | 378.4          | 0.080                  | 200.0            | 0.13         |
| OCV INLET  | 1857.3           | 459.7          | 44.7                   | 200.0            | 13.82        |
| OCV EXIT   | 1300.1           |                | 44.7                   | 200.0            | 10.00        |
| CHAMBER INJ  | 1287.1           | 440.9          | 44.7                   | 200.0            | 9.91         |
| CHAMBER  | 1158.7           |                |                        |                  |              |
| CHAPIDEN   |                  |                |                        |                  |              |
|  |                  | VALVE DA       | TA #                   |                  |              |
|  |                  |                |                        |                  |              |
| VALVE  | DELTA P          | AREA           | FLOH                   | * BYPASS         |              |
| OTBV   | 2514.            |                | 2.01                   | 5.00             |              |
| TBV  | 798.             | 0.03           | 0.37                   | 5.00             |              |
| FSOV   | 32.              | 2.49           | 7.44                   |                  |              |
| OBTV   | 2474.            | 0.04           | 4.47                   |                  |              |
| OCV  | 557.             | 0.76           | 44.65                  |                  |              |
| J  |                  |                |                        |                  |              |
|  |                  | INJECTOR       | DATA =                 |                  |              |
|  |                  |                |                        |                  |              |
| INJECTOR   | DELTA P          | AREA           | FLOH                   | VEFOCITA         |              |
| FUEL   | 88.              |                |                        | 1093.33          |              |
| LOX  | 128.             | 1.87           | 44.65                  | 330.17           |              |
| con  |                  |                |                        |                  |              |

TABLE 21. — DUAL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|                                     |                | HERRY PERFORMANCE D  |                 |                 |
|-------------------------------------|----------------|----------------------|-----------------|-----------------|
|                                     |                | MINERT PERFORMANCE D |                 |                 |
|                                     |                |                      | ********        |                 |
| # H2 BOOST TU                       |                |                      | H2 BOOST P      |                 |
| *******                             |                |                      |                 |                 |
| EFFICIENCY (T/T)                    |                | EFF10                |                 | 0.766           |
| EFFICIENCY (T/S)                    |                |                      | POWER           | 48.             |
|                                     | 41240.         |                      | (RPH)           | 41240.          |
| MEAN DIA (IN)                       | 1.45           | S SPE                | ED              | 3049.           |
| EFF AREA (IN2)                      | 2.93           | HEAD                 | (FT)            | 2690.           |
| U/C (ACTUAL)                        | 0.534          | DIA.                 | CIND            | 2.44            |
| MAX TIP SPEED                       | 376.           | TIP S                | PEED            | 439.            |
| STAGES                              | 1              |                      | FLOH            | 763.            |
| GAJTHA                              | 1.41           | HEAD                 |                 | 0.450           |
| PRESS RATIO (T/T)                   |                | FLOH                 | COEF            | 0.201           |
| PRESS RATIO (T/S)                   | 1.03           |                      |                 |                 |
| HORSEPOHER EXIT MACH NUMBER         |                |                      |                 |                 |
| SPECIFIC SPEED                      | 0.13<br>150.00 |                      |                 |                 |
| SPECIFIC DIAMETER                   |                |                      |                 |                 |
| STEEL TE DIMILIER                   | 0.34           |                      |                 |                 |
| **********                          |                |                      | *******         | **              |
| # H2 TURBINE                        |                |                      | * H2 PUMP       |                 |
|                                     |                |                      | ******          |                 |
|                                     |                |                      | STAGE ONE       |                 |
|                                     |                |                      | *******         |                 |
| EFFICIENCY (T/T)                    |                |                      | 0.738           |                 |
| EFFICIENCY (T/S)                    |                | HORSEPOHER           | 697.            |                 |
|                                     | 125000.        | SPEED (RPM)          | 125000.         | 125000.         |
| HORSEPOHER                          | 1393.          | SS SPEED             | 11361.          |                 |
| MEAN DIA. (IN)                      |                | S SPEED              | 1255.<br>37909. |                 |
| EFF AREA (IN2)                      |                |                      | 2.89            |                 |
| MAX TIP SPEED                       | 1577.          | TIP SPEED            | 1578.           | 1577.           |
| STAGES                              | 1              | VOL. FLON            | 744.            | 730.            |
| GAPPIA                              | 1.41           | HEAD COEF            | 0.490           | 0.489           |
| PRESS RATIO (T/T)                   |                | FLON COEF            | 0.126           |                 |
| PRESS RATIO (T/S)                   |                | DIAMETER RATIO       | 0.436           |                 |
| EXIT MACH NUMBER                    | 0.22           | BEARING DN           | 3.00E+06        |                 |
| SPECIFIC SPEED                      | 57.47          | SHAFT DIAMETER       | 24.00           |                 |
| SPECIFIC DIAMETER                   | 1.42           |                      |                 |                 |
|                                     |                |                      |                 |                 |
|                                     |                |                      | *********       |                 |
| # O2 BOOST TUP                      |                |                      | D2 BOOST P      |                 |
| EFFICIENCY (T/T)                    |                |                      | IENCY           | 0.764           |
| EFFICIENCY (T/S)                    |                |                      | POHER           | 26.             |
| SPEED (RPM)                         |                |                      | (RPM)           | 11053.          |
| MEAN DIA (IN)                       |                | S SPE                |                 | 3026.           |
| EFF AREA (IN2)                      | 0.22           | HEAD                 | (FT)            | 242.            |
| U/C (ACTUAL)                        | 0.553          | DIA.                 | (IH)            | 2.72            |
| MAX TIP SPEED                       | 261.           | TIP S                |                 | 132.            |
| STAGES                              | 1              | VOL.                 |                 | 282.            |
| GAIPIA                              | 1.85           | HEAD                 |                 | 0.450           |
| PRESS RATIO (T/T) PRESS RATIO (T/S) |                | FLON                 | CUEF            | 0.200           |
| HORSEPOHER                          | 26.            |                      |                 |                 |
| EXIT MACH NUMBER                    | 0.02           |                      |                 |                 |
| SPECIFIC SPEED                      | 38.43          |                      |                 |                 |
| SPECIFIC DIAMETER                   |                |                      |                 |                 |
|                                     |                |                      |                 |                 |
| *********                           |                |                      | ********        |                 |
| # 02 TURBINE #                      | •              |                      | ■ 02 PUMP       |                 |
| *********                           |                |                      | ********        |                 |
| EFFICIENCY (T/T)                    |                |                      | IENCY           | 0.737           |
| EFFICIENCY (T/S)                    |                |                      | POHER           | 1018.           |
|                                     | 82933.         | SPEED<br>SS SP       | (RPM)           | 82933.<br>27218 |
| HORSEPONER HEAN DIA (IN)            | 1018.          | 55 SPE               |                 | 27218.<br>1471. |
| EFF AREA (IN2)                      |                | S SPE                |                 | 9227.           |
| U/C (ACTUAL)                        |                |                      | (IN)            | 2.22            |
| MAX TIP SPEED                       | 612.           | TIP S                |                 | 804.            |
| STAGES                              | 1              | VOL.                 |                 | 279.            |
| GAMMA                               | 1.85           | HEAD                 |                 | 0.459           |
| PRESS RATIO (T/T)                   | 2.07           | FLOH                 |                 | 0.137           |
| PRESS RATIO (T/S)                   | 2.37           | DIAHE                | TER RATIO       | 0.671           |
| EXIT MACH NUMBER                    | 0.35           |                      | NG DN           |                 |
| SPECIFIC SPEED                      |                | SHAFT                | DIAMETER        | 18.00           |
| SPECIFIC DIAMETER                   | 1.01           |                      |                 |                 |
|                                     |                |                      |                 |                 |

# TABLE 22. — DUAL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER)

# ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE            | 1075.9 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 37500. |
| TOTAL ENGINE FLOW RATE      | 78.15  |
| DEL. VAC. ISP               | 479.9  |
| THROAT AREA                 | 16.99  |
| HOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 147.09 |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA CP                      | 0.993  |
| CHAMBER COOLANT DP          | 279.   |
| CHAMBER COOLANT DT          | 317.   |
| NOZZLE COOLANT DP           | 240.   |
| NOZZLE COOLANT DT           | 326.   |
| CHAMBER Q (HYDROGEN COOLED) | 13588. |
| NOZZLE Q (OXYGEN COOLED)    | 8378.  |

## ENGINE STATION CONDITIONS

|                 | • FUEL | 2A21EM CO | NDITIONS . |          |        |
|-----------------|--------|-----------|------------|----------|--------|
| STATION         | PRESS  | TEMP      | FLOM       | ENTHALPY | DENSIT |
| B.P. INLET      | 18.6   | 37.4      | 11.19      | -107.5   | 4.37   |
| B.P. EXIT       | 100.3  | 38.5      | 11.19      | -103.0   | 4.39   |
| PUMP INLET      | 100.3  | 38.5      | 11.19      | -103.0   | 4.39   |
| IST STAGE EXIT  | 1139.0 | 50.0      | 11.19      | -46.5    | 4.51   |
| PUMP EXIT       | 2200.4 | 61.2      | 11.19      | 10.2     | 4.61   |
| COOLANT INLET   | 2178.4 | 61.4      | 11.19      | 10.2     | 4.59   |
| COOLANT EXIT    | 1899.3 | 378.0     | 11.19      | 1224.6   | 0.84   |
| TBV INLET       | 1880.3 | 378.0     | 0.56       | 1224.6   | 0.85   |
| TBV EXIT        | 1197.8 | 379.4     | 0.56       | 1224.6   | 0.56   |
| H2 TRB INLET    | 1880.3 | 378.0     | 10.63      | 1224.6   | 0.85   |
| H2 TRB EXIT     | 1284.1 | 349.2     | 10.63      | 1105.4   | 0.65   |
| H2 TRB DIFFUSER | 1243.7 | 349.2     | 10.63      | 1105.4   | 0.63   |
| H2 BST TRB IN   | 1231.5 | 349.2     | 10.63      | 1105.4   | 0.63   |
| H2 BST TRB OUT  | 1211.1 | 348.1     | 10.63      | 1100.6   | 0.62   |
| H2 BST TRB DIFF | 1197.8 | 348.1     | 10.63      | 1100.6   | 0.61   |
| H2 TANK PRESS   | 18.6   | 350.3     | 0.0257     | 1106.8   | 0.0100 |
| FSOV INLET      | 1197.B | 349.7     | 11.16      | 1106.8   | 0.61   |
| FSOV EXIT       | 1167.9 | 349.7     | 11.16      | 1106.8   | 0.59   |
| CHAMBER INJ     | 1156.2 | 349.7     | 11.16      | 1106.8   | 0.59   |
| CHAMBER         | 1075.9 |           |            |          |        |

|                 | <ul> <li>OXY</li> </ul> | GEN SYSTEM | CONDITIONS | 5 •      |         |
|-----------------|-------------------------|------------|------------|----------|---------|
| STATION         | PRESS                   | TEMP       | FLON       | ENTHALPY | DENSITY |
| B.P. INLET      | 16.D                    | 162.7      | 67.1       | 61.l     | 71.17   |
| B.P. EXIT       | 135.6                   | 163.2      | 67.1       | 61.5     | 71.20   |
| PUMP INLET      | 135.6                   | 163.2      | 67.1       | 61.5     | 71.20   |
| PUMP EXIT       | 4640.2                  | 183.6      | 67.1       | 76.9     | 72.08   |
| COOLANT INLET   | 4593.8                  | 183.8      | 67.1       | 76.9     | 72.01   |
| COOLANT EXIT    | 4353.9                  | 509.5      | 67.1       | 201.7    | 26.47   |
| OTBV INLET      | 4353.9                  | 509.5      | 3.0        | 201.7    | 26.47   |
| OTBV EXIT       | 1815.9                  | 464.2      | 3.0        | 201.7    | 13.30   |
| 02 TRB INLET    | 4353.9                  | 509.5      | 57.4       | 201.7    | 26.47   |
| 02 TRB EXIT     | 2016.1                  | 416.3      | 57.4       | 183.6    | 18.20   |
| 02 TRB DIFFUSER | 1815.9                  | 409.8      | 57.4       | 183.6    | 16.70   |
| 02 BST TRB IN   | 4353.9                  | 509.5      | 6.7        | 201.7    | 26.47   |
| O2 BST TRB DUT  | 4312.6                  | 496.8      | 6.7        | 197.6    | 27.23   |
| 02 BST TRB DIFF | 4310.9                  | 496.8      | 6.7        | 197.6    | 27.22   |
| OBTY INLET      | 4510.9                  | 496.8      | 6.7        | 197.6    | 27.22   |
| OBTY EXIT       | 1815.9                  | 450.9      | 6.7        | 197.6    | 13.93   |
| MIXER           | 1815.9                  | 415.8      | 67.0       | 185.9    | 16.19   |
| OZ TANK PRESS   | 16.0                    | 313.7      | 0.144      | 185.9    | 0.15    |
| OCY INLET       | 1725.1                  | 412.6      | 67.0       | 185.9    | 15.49   |
| OCV EXIT        | 1207.6                  | 391.5      | 67.0       | 185.9    | 11.27   |
| CHAMBER INJ     | 1195.5                  | 390.9      | 67.0       | 185.9    | 11.17   |
| CHAMBER         | 1075.9                  |            |            |          |         |

#### # VALVE DATA #

| VALVE<br>OTBV | DELTA P<br>2538. | AREA<br>0.03 | FLOH<br>3.02 | % BYPASS<br>5.00 |
|---------------|------------------|--------------|--------------|------------------|
| TBV           | 683.             | 8.04         | 0.56         | 5.00             |
| FSOV          | 30.              | 3.86         | 11.16        |                  |
| OBTV          | 2495.            | 0.06         | 6.71         |                  |
| OCV           | 518.             | 1.12         | 66.98        |                  |

#### . INJECTOR DATA .

| INJECTOR | DELTA P | AREA | FLOM  | VELOCITY |
|----------|---------|------|-------|----------|
| FUEL     | 80.     | 2.46 | 11.16 | 1034.90  |
| LOX      | 120.    | 2.74 | 66.98 | 300.13   |

TABLE 22. — DUAL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|                              |               |                | **********                   |                   |                  |
|------------------------------|---------------|----------------|------------------------------|-------------------|------------------|
|                              |               | TURBOMAC       | HINERY PERFORMANCE           | DATA =            |                  |
|                              |               | *******        | **************               | *****             |                  |
|                              |               | ******         |                              | ********          |                  |
|                              |               | RBINE *        |                              | H2 B00\$T         |                  |
| EFF1C1ENCY                   |               |                |                              | CIENCY            |                  |
| EFF1C1ENCY                   |               |                |                              | EPOHER            | 0.766<br>71.     |
| SPEED                        | (RPM)         | 33632.         |                              | D (RPM)           |                  |
| MEAN DIA                     | (IN)          |                | \$ 59                        |                   | 3051.            |
| EFF AREA                     | (IN2)         |                | HEAD                         |                   |                  |
| U/C (/<br>MAX TIP SPE        | ACTUAL)       | 0.530<br>373.  | DIA.                         |                   |                  |
| STAGES                       | LED           | 3/3.           |                              | SPEED<br>FLOH     | 438.             |
| GAMMA                        |               | 1.37           |                              | COEF              | 1144.<br>0.450   |
| PRESS RATIO                  |               | 1.02           |                              | COEF              | 0.201            |
| PRESS RATIO                  |               | 1.03           |                              |                   |                  |
| HORSEPOHER                   |               | 71.            |                              |                   |                  |
| SPECIFIC SP                  |               | 0.13<br>150.00 |                              |                   |                  |
| SPECIFIC DI                  |               |                |                              |                   |                  |
|                              |               |                |                              |                   |                  |
| ****                         |               |                |                              | ******            | ***              |
| * H2 TU                      |               |                |                              | # H2 PUM          |                  |
|                              |               | •              |                              | ******            |                  |
|                              |               |                |                              | STAGE ON          |                  |
| EFFICIENCY                   | (1/1)         | 0.884          | EFFICIENCY                   | 0.760             |                  |
| EFFICIENCY                   | (T/S)         | 0.799          |                              | 895.              | 898.             |
| SPEED                        |               |                | SPEED (RPH)                  | 107143.           | 107143.          |
| HORSEPOHER                   |               | 1793.          | SS SPEED                     | 11948.            |                  |
| MEAN DIA.<br>EFF AREA        | (IN)<br>(IN2) |                | S SPEED                      | 1446.             |                  |
|                              |               | 0.553          | HEAD (FT)<br>DIA. (IN)       | 33431.<br>3.22    |                  |
| MAX TIP SPE                  | ED            | 1488.          | TIP SPEED                    | 1508.             |                  |
| STAGES                       |               | 1              | VOL. FLOM                    | 1113.             | 1090.            |
| GAMMA                        |               | 1.37           | HEAD COEF                    | 0.473             |                  |
| PRESS RATIO                  |               |                | FLON COEF                    | 0.136             |                  |
| EXIT MACH N                  |               | 1.53<br>0.23   | DIAMETER RATIO<br>BEARING IN |                   |                  |
| SPECIFIC SPE                 |               | 67.54          | SHAFT DIAMETER               | 3.00E+04<br>28.00 |                  |
| SPECIFIC DIA                 |               | 1.23           |                              | 20.00             |                  |
| ******                       |               |                |                              |                   |                  |
| * 02 BOO                     |               |                |                              | 02 BOOST P        |                  |
| ****                         |               |                |                              | 02 DOG: P         |                  |
| EFFICIENCY                   |               |                |                              | IENCY             | 0.764            |
| EFFICIENCY                   |               |                |                              | POHER             | 39.              |
| SPEED<br>MEAN DIA            | (RPM)         | 9023.          |                              | (RPM)             | 9023.            |
|                              | (IN2)         | 6.34<br>0.31   | S SPEI<br>HEAD               |                   | 3026.            |
|                              | TUAL )        |                | DIA.                         | (FT)<br>(IN)      | 242.<br>3.34     |
| MAX TIP SPEE                 | D             | 260.           | TIP SI                       |                   | 132.             |
| STAGES                       |               | 1              | VOL. I                       |                   | 423.             |
| GANMA<br>PRESS RATIO         | (7/7)         | 1.95           | HEAD (                       |                   | 0.450            |
| PRESS RATIO                  |               |                | FLOH (                       | JUEP              | B.200            |
| HORSEPOHER                   |               | 39.            |                              |                   |                  |
| EXIT MACH NU<br>SPECIFIC SPE | MBER          | 0.02           |                              |                   |                  |
|                              |               |                |                              |                   |                  |
| SPECIFIC DIA                 | mt IER        | 2.12           |                              |                   |                  |
| *****                        | *****         |                |                              | ********          |                  |
| # 02 TUR                     |               |                |                              | 02 PUHP           |                  |
|                              |               |                |                              | *******           | •                |
| EFFICIENCY<br>EFFICIENCY     | (T/T)         | 0.887          | EFFICI                       |                   | 0.751            |
|                              | (RPH)         |                | HORSEP                       | OHER              | 1463.            |
| HORSEPOHER                   |               | 1463.          | 27 CDE                       | (RPM)<br>FD       | 66685.<br>26810. |
| MEAN DIA .                   | (IN)          | 1.80           | S SPEE                       | ED<br>D           | 1476.            |
| EFF AREA                     | ( IN2 )       | 0.48           |                              | (FT)<br>(IN)      | 8996.            |
| U/C (AC                      |               |                |                              |                   | 2.71             |
| MAX TIP SPEEL<br>STAGES      | D             | 598.           | TIP SP                       | EED               | 790.             |
| STAGES<br>GAMMA              |               | 1<br>1.95      | VOL. F                       |                   | 418.             |
| PRESS RATIO                  | (T/T)         | 2.16           | HEAD C<br>FLOH C             |                   | 0.464<br>0.138   |
| PRESS RATIO                  | (T/S)         | 2.49           |                              | ER RATIO          | 0.138            |
| EXIT MACH NUM                |               | 0.36           | BEARIN                       | G DN              |                  |
| SPECIFIC SPEE                |               | 83.50          | SWFT                         | DIAMETER          | 22.00            |
| SPECIFIC DIAM                | TEICH         | 1.02           |                              |                   |                  |
|                              |               |                |                              |                   |                  |

# TABLE 23. — DUAL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER TUBE CHAMBER)

## ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE            | 1042.6 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 50000. |
| TOTAL ENGINE FLON RATE      | 104.20 |
| DEL. VAC. ISP               | 479.8  |
| THROAT AREA                 | 23.37  |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 172.52 |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C#                      | 0.993  |
| CHAMBER COOLANT DP          | 243.   |
| CHAMBER COOLANT DT          | 296.   |
| NOZZLE COOLANT DP           | 263.   |
|                             | 306.   |
| CHAMBER Q (HYDROGEN COOLED) | 16868. |
| HOZZLE Q (DXYGEN COOLED)    | 10504. |

### ENGINE STATION CONDITIONS

|                 | * FUEL | SYSTEM CON | OITIONS . |          |         |
|-----------------|--------|------------|-----------|----------|---------|
|                 | PRESS  | TEMP       | FLON      | ENTHALPY | DENSITY |
| STATION         | 18.6   | 37.4       | 14.92     | -107.5   | 4.37    |
| B.P. INLET      | 100.8  | 38.5       | 14.92     | -103.0   | 4.39    |
| B.P. EXIT       | 100.8  | 38.5       | 14.92     | -103.0   | 4.39    |
| PUMP INLET      | 1093.9 | 49.2       | 16.92     | -49.8    | 4.52    |
| IST STAGE EXIT  |        | 59.6       | 14.92     | 3.8      | 4.62    |
| . PUMP EXIT     | 2113.5 | 59.8       | 14.92     | 3.8      | 4.61    |
| COOLANT INLET   | 2092.4 |            | 14.92     | 1134.2   | 0.89    |
| COOLANT EXIT    | 1849.0 | 355.5      | 0.75      | 1134.2   | 0.88    |
| TBV INLET       | 1830.5 | 355.5      | 0.75      | 1134.2   | 0.58    |
| TBV EXIT        | 1162.0 | 356.6      | 14.18     | 1134.2   | 0.88    |
| H2 TRB INLET    | 1830.5 | 355.5      | 14.18     | 1021.8   | 0.67    |
| H2 TRB EXIT     | 1252.7 | 328.3      |           | 1021.B   | 0.65    |
| H2 TRB DIFFUSER | 1207.8 | 328.3      | 14.18     | 1021.8   | 0.65    |
| HZ BST TRB IN   | 1195.7 | 328.3      | 14.18     |          | 0.64    |
| H2 BST TRB OUT  | 1175.1 | 327.2      | 14.18     | 1017.0   | 0.63    |
| H2 BST TRB DIFF | 1162.0 | 327.2      | 14.18     | 1017.0   |         |
| HZ TANK PRESS   | 18.6   | 328.6      | 0.0364    | 1022.9   | 0.0107  |
| FSOV INLET      | 1162.0 | 328.6      | 14.89     | 1022.9   | 0.63    |
| FSOV EXIT       | 1133.0 | 328.7      | 14.89     | 1022.9   | 0.61    |
| CHAMBER INJ     | 1121.6 | 328.7      | 14.89     | 1022.9   | 0.61    |
| CHAMBER         | 1042.6 |            |           |          |         |

|                 | N DXYC           | EN SYSTEM | CONDITIONS | ; »      |         |
|-----------------|------------------|-----------|------------|----------|---------|
| STATION         | PRESS            | TEMP      | FLOH       | ENTHALPY | DENSITY |
|                 | 16.0             | 162.7     | 89.5       | 61.1     | 71.17   |
| B.P. INLET      | 135.6            | 163.2     | 89.5       | 61.5     | 71.20   |
| B.P. EXIT       | 135.6            | 163.2     | 87.5       | 61.5     | 71.20   |
| PUMP INLET      | 4813.6           | 183.9     | 89.5       | 77.3     | 72.17   |
| PUMP EXIT       | 4765.5           | 184.2     | 89.5       | 77.3     | 72.10   |
| COOLANT INLET   | 4502.3           | 489.7     | 89.5       | 194.6    | 28.70   |
| COOLANT EXIT    |                  | 489.7     | 4.0        | 194.6    | 28.70   |
| OTBV INLET      | 4502.3<br>1759.3 | 439.8     | 4.0        | 194.6    | 14.02   |
| OTBY EXIT       |                  | 489.7     | 76.5       | 194.6    | 28.70   |
| 02 TRB INLET    | 4502.3<br>1964.3 | 394.8     | 76.5       | 176.1    | 19.87   |
| 02 TRB EXIT     |                  | 387.8     | 76.5       | 176.1    | 18.21   |
| 02 TRB DIFFUSER | 1759.3           | 489.7     | 9.0        | 194.6    | 28.70   |
| 02 BST TRB IN   | 4502.3           | 477.3     | 9.0        | 190.5    | 29.58   |
| 02 BST TRB DUT  | 4458.1           | 477.3     | 9.0        | 190.5    | 29.57   |
| 02 BST TRB DIFF | 4456.4           | 477.3     | 9.0        | 190.5    | 29.57   |
| OSTV INLET      | 4456.4           | 427.3     | 9.0        | 190.5    | 14.78   |
| OBTV EXIT       | 1759.3           | 393.8     | 89.3       | 178.4    | 17.59   |
| MIXER           | 1759.3           | 279.6     | 0.217      | 178.4    | 0.17    |
| 02 TANK PRESS   | 16.0             | 390.5     | 89.3       | 178.4    | 16.85   |
| OCV INLET       | 1671.4           | 368.2     | 89.3       | 178.4    | 12.33   |
| OCV EXIT        | 1169.9           |           | 89.3       | 178.4    | 12.22   |
| CHAMBER INJ     | 1158.2           | 367.6     | •7.3       |          |         |
| CHAMBED         | 1042.6           |           |            |          |         |

# CHAMBER 1042.6 \* VALVE DATA \* VALVE DELTA P AREA FLOM % BYPASS OTBV 2743. 0.03 4.03 5.00 TBV 668. 0.06 0.75 5.00 FSOV 29. 5.14 14.89 OBTV 2697. 0.07 8.95 OCV 501. 1.45 89.31 \*\* INJECTOR DATA \*\*

| INJECTOR | DELTA P | AREA | FLON  | VELOCITY |
|----------|---------|------|-------|----------|
| FUEL     | 79.     | 3.26 | 14.89 | 1012.37  |
| OX       | 116.    | 3.56 | 89.31 | 282.09   |

TABLE 23. — DUAL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|                                     |                   | ************************************** |                  |                   |
|-------------------------------------|-------------------|--|------------------|-------------------|
|                                     |                   | ***********                            |                  |                   |
|                                     |                   |  | ********         | * # # #           |
| # H2 BOOST TU                       |                   |  | H2 800ST PU      | MP #              |
| ***********                         |                   |  | ********         | 3 5 E N           |
| EFFICIENCY (T/T)                    | 0.849             | EFF I                                  | CIENCY           | 0.765             |
| EFFICIENCY (T/S)                    | 0.458             |  | EPOHER           | 96.               |
|                                     | 29203.            |  | D (RPH)          | 29203.            |
| MEAN DIA (IN)                       | 2.02              |  | EED              | 3046.             |
| EFF AREA (IN2)                      |                   | HEAD                                   |                  | 2700.             |
| U/C (ACTUAL)                        |                   | DIA.                                   |                  | 3.45              |
| MAX TIP SPEED                       | 370.              |  | SPEED            | 439.<br>1526.     |
| STAGES                              | 1                 |  | FLON             | 0.450             |
| GAMMA                               | 1.40<br>1.02      |  | COEF             | 0.201             |
| PRESS RATIO (T/T) PRESS RATIO (T/S) |                   | 7.00                                   | · COCI           |                   |
| HORSEPOHER                          | 96.               |  |                  |                   |
| EXIT MACH NUMBER                    |                   |  |                  |                   |
| SPECIFIC SPEED                      |                   |  |                  |                   |
| SPECIFIC DIAMETER                   |                   |  |                  |                   |
|                                     |                   |  |                  |                   |
| *********                           | •                 |  | ********         |                   |
| * H2 TURBINE                        | •                 |  | H2 PUMP          |                   |
| **********                          | •                 |  | *******          |                   |
|                                     |                   |  | STAGE ONE        |                   |
|                                     |                   |  | 0.771            |                   |
| EFFICIENCY (T/T)                    |                   | EFFICIENCY                             | 1123.            | 1131.             |
| EFFICIENCY (T/S)                    | 0.796             | HORSEPOHER<br>SPEED (RPM)              | 100000.          | 100000.           |
| SPEED (RPM)                         | 2254.             | SS SPEED (RPH)                         | 12825.           |                   |
| HORSEPOMER<br>MEAN DIA. (IN)        |                   | S SPEED                                | 1612.            | 1588.             |
| EFF AREA (IN2)                      |                   |  | 31936.           | 32103.            |
|                                     | 0.553             | DIA. (IN)                              | 3.44             | 3.44              |
| MAX TIP SPEED                       | 1464.             | TIP SPEED                              | 1501.            | 1501.             |
| STAGES                              | 1                 | VOL. FLOH                              | 1483.            | 1450.             |
| GAMMA                               | 1.40              |  | 0.456            | 0.458             |
| PRESS RATIO (T/T)                   | 1.46              | FLOH COEF                              | 0.144            |                   |
| PRESS RATIO (T/S)                   |                   | DIAMETER RATIO                         | 0.505            |                   |
| EXIT MACH NUMBER                    |                   | BEARING DN                             | 3.00E+06         |                   |
| SPECIFIC SPEED                      | 74.45             | SHAFT DIAMETER                         | R 30.00          |                   |
| SPECIFIC DIAMETER                   | 1.13              |  |                  |                   |
| ********                            |                   |  |                  |                   |
| 02 BOOST TO                         |                   |  | 02 BOOST PI      |                   |
| * 02 80031 10                       |                   |  |                  |                   |
| EFFICIENCY (T/T)                    |                   | EFF                                    | ICIENCY          | 0.764             |
| EFFICIENCY (T/S)                    |                   |  | SEPONER          | 52.               |
| SPEED (RPM)                         |                   | SPE                                    | ED (RPM)         | 7013.             |
| MEAN DIA (IN)                       | 7.32              |  | PEED             | 3026.             |
| EFF AREA (1N2)                      |                   | HEA                                    | D (FT)           | 242.              |
| U/C (ACTUAL)                        |                   | DIA                                    |                  | 3.85<br>132.      |
| MAX TIP SPEED                       | 260.              |  | SPEED            | 564.              |
| STAGES                              | 1                 |  | . FLON<br>D COEF | 0.450             |
| GAMMA PRESS RATIO (T/T)             | 1.98              |  | H COEF           | 0.200             |
| PRESS RATIO (T/S                    |                   | ,,,,                                   |                  | -                 |
| HORSEPONER                          | 52.               |  |                  |                   |
| EXIT MACH NUMBER                    |                   |  |                  |                   |
| SPECIFIC SPEED                      | 36.25             |  |                  |                   |
| SPECIFIC DIAMETER                   | 2.19              |  |                  |                   |
|                                     |                   |  |                  | _                 |
| **********                          |                   |  | ********         |                   |
| # 02 TURBINE                        |                   |  | * OZ PUMP        |                   |
| **********                          |                   |  | ICIENCY          | 0.758             |
| EFFICIENCY (T/T                     |                   |  | SEPOHER          | 2003.             |
| EFFICIENCY (T/S                     |                   |  | ED (RPM)         | 58298.            |
| SPEED (RPM<br>HORSEPOHER            | ) 58298.<br>2003. |  | SPEED            | 27067.            |
| MEAN DIA (IN                        |                   |  | PEED             | 1449.             |
| EFF AREA (IN2                       |                   | HEA                                    |                  | 9330.             |
|                                     | 0.553             | DIA                                    |                  | 3.14              |
| MAX TIP SPEED                       | 603.              | TIP                                    | SPEED            | 799.              |
| STAGES                              | 1                 | -                                      | . FLOH           | 557.              |
| GAMMA                               | 1.98              |  | D COEF           | 0.470             |
| PRESS RATIO (T/T                    |                   |  | H COEF           | 0.136             |
| PRESS RATIO (T/S                    |                   |  | METER RATIO      | 0.671             |
| EXIT MACH NUMBER                    |                   |  | RING DN          | 1.40E+06<br>24.00 |
| SPECIFIC SPEED                      |                   | SHA                                    | FT DIAMETER      | 24.00             |
| SPECIFIC DIAMETE                    | R 1.04            |  |                  |                   |

TABLE 24. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR - 7500 LBF THRUST (COPPER TUBE CHAMBER)

| ENGINE | PERFORMANCE | PARAMETERS |
|--------|-------------|------------|
|        |             |            |

| CHAMBER PRESSURE       | 1941.3 |
|------------------------|--------|
| VAC ENGINE THRUST      | 7500.  |
| TOTAL ENGINE FLON RATE | 15.62  |
| DEL. VAC. ISP          | 480.1  |
| THROAT AREA            | 1.89   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 49.07  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C#                 | 0.993  |
| CHAMBER COOLANT DP     | 1386.  |
| CHAMBER COOLANT DT     | 796.   |
| NOZZLE/CHAMBER Q       | 6383.  |

| ENGINE STATION CONDITIONS |         |            |            |           |         |  |
|---------------------------|---------|------------|------------|-----------|---------|--|
|                           | • FUEL  | SYSTEM CO  | NDITIONS . |           |         |  |
| STATION                   | PRESS   | TEMP       | FLOH       | ENTHALPY  | DENSITY |  |
| B.P. INLET                | 18.6    | 37.4       | 2.23       | -107.5    | 4.37    |  |
| B.P. EXIT                 | 100.6   | 38.5       | 2.23       | -103.0    | 4.39    |  |
| PUMP INLET                | 100.6   | 38.5       | 2.23       | -103.0    | 4.39    |  |
| IST STAGE EXIT            | 2202.9  | 78.4       | 2.23       | 58.1      | 4.15    |  |
| 2ND STAGE EXIT            | 4183.0  | 114.8      | 2.23       | 210.1     | 4.11    |  |
| PUMP EXIT                 | 6085.6  | 147.1      | 2.23       | 354.6     | 4.15    |  |
| COLD REGEN IN             | 6024.8  | 147.6      | 2.23       | 354.6     | 4.13    |  |
| COLD REGEN EX             | 5964.5  | 369.0      | 2.23       | 1247.9    | 2.24    |  |
| COOLANT INLET             | 5964.5  | 369.0      | 2.23       | 1247.9    | 2.24    |  |
| COOLANT EXIT              | 4578.7  | 1165.3     | 2.23       | 4105.7    | 0.67    |  |
| TBV INLET                 | 4532.9  | 1165.6     | 0.11       | 4105.7    | 0.67    |  |
| TBV EXIT                  | 2241.0  | 1182.1     | 0.11       | 4105.7    | 0.34    |  |
| 02 TRB INLET              | 4552.9  | 1165.6     | 2.12       | 4105.7    | 0.67    |  |
| OZ TRB EXIT               | 4280.2  | 1148.1     | 2.12       | 4035.8    | 0.63    |  |
| H2 TRB INLET              | 4200.2  | 1148.1     | 2.12       | 4035.8    | 0.63    |  |
| H2 TRB EXIT               | 2361.2  | 1923.6     | 2.12       | 3553.8    | 0.41    |  |
| H2 TRB DIFFUSER           | 2335.7  | 1023.8     | 2.12       | 3553.8    | 0.41    |  |
| H2 BST TRB IN             | 2312.4  | 1023.8     | 2.12       | 3553.8    | 0.41    |  |
| H2 BST TRB OUT            | 2298.6  | 1022.7     | 2.32       | 3549.0    | 0.40    |  |
| H2 BST TRB DIFF           | 2283.7  | 1022.8     | 2.12       | 3549.0    | 0.40    |  |
| O2 BST TRB IN             | 2260.8  | 1023.6     | 2.12       | 3549.0    | 0.39    |  |
| O2 BST TRB OUT            | 2253.6  | 1022.3     | 2.12       | 3546.5    | 0.39    |  |
| O2 BST TRB DIFF           | 2252.2  | 1022.3     | 2.12       | 3546.5    | 0.39    |  |
| H2 TANK PRESS             | 18.6    | 1044.2     | 0.0017     | 3574.4    | 0.0033  |  |
| GOX HEAT EXCH IN          |         | 1030.4     | 2.23       | 3574.4    | 0.39    |  |
| GOX HEAT EXCH DUT         | 2229.8  | 1030.1     | 2.23       | 3573.1    | 0.39    |  |
| HOT REGEN IN              | 2229.8  | 1030.1     | 2.23       | 3573.1    | 0.39    |  |
| HOT REGEN EX              | 2162.9  | 775.9      | 2.23       | 2679.1    | 0.49    |  |
| FSOV INLET                | 2162.9  | 775.9      | 2.23       | 2679.1    | 0.49    |  |
| FSOV EXIT                 | 2108.8  | 776.2      | 2.23       | 2679.1    | 0.48    |  |
| CHAMBER INJ               | 2086.8  | 776.4      | 2.23       | 2679.1    | 0.47    |  |
| CHAMBER                   | 1941.3  |            |            |           |         |  |
|                           | * DXY   | GEN SYSTEM | CONDITIONS | s •       |         |  |
| STATION                   | PRESS   | TEMP       | FLOW       | ENTHALPY  | DENSITY |  |
| B.P. INLET                | 16.8    | 162.7      | 13.4       | 61.1      | 71.17   |  |
| B.P. EXIT                 | 135.6   | 163.2      | 13.4       | 61.5      | 71.20   |  |
| PUMP INLET                | 135.6   | 163.2      | 13.4       | 61.5      | 71.20   |  |
| PUMP EXIT                 | 3143.9  | 178.8      | 13.4       | 72.5      | 71.53   |  |
| OZ TANK PRESS             | 16.0    | 400.0      | 0.023      | 204.7     | 0.12    |  |
| OCV INLET                 | 3112.5  | 179.0      | 13.4       | 72.5      | 71.48   |  |
| OCV EXIT                  | 2178.7  | 182.6      | 13.4       | 72.5      | 70.04   |  |
| CHAMBER INJ               | 2135.4  | 182.8      | 13.4       | 72.5      | 69.97   |  |
| CHAMBER                   | 1941.3  |            |            |           |         |  |
| * VALVE DATA *            |         |            |            |           |         |  |
| VALVE                     | DELTA P | AREA       | FLON       | * BYPASS  |         |  |
| TBV                       | 2292.   | 0.01       | 0.11       | 5.00      |         |  |
| FSOV                      | 54.     | 0.64       | 2.23       | 3.00      |         |  |
| ocv                       | 934.    | 0.08       | 13.39      |           |         |  |
|                           |         |            |            |           |         |  |
| THE ISCTOR                |         | INJECTOR I |            | UEL OCTTV |         |  |
| INJECTOR                  | DELTA P | AREA       | FLDM       | VELOC1TY  |         |  |
| FUEL                      | 146.    | 0.44       | 2.23       | 1558.24   |         |  |
| LDX                       | 216.    | 0.17       | 13.39      | 160.32    |         |  |

TABLE 24. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 7500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| •  |  |                                | (00111          |
|--|--|--------------------------------|-----------------|
| PPEREASERES  | *****************                                  |                                |                 |
| ***************************************                            | MERY PERFORMANCE DATA &                            |                                |                 |
| *************  |  |                                |                 |
| # H2 BOOST TURBINE #   | # H2 BOOS  | T PUPP +                       |                 |
| **************   | *******  | *******                        |                 |
| EFFICIENCY (1/1) 0.789<br>EFFICIENCY (1/5) 0.322                   | EFF1C1DICY<br>HORSEPOILER                          | 9.766                          |                 |
| SPEED (RPH) 75396.   | HORSEPONER<br>SPEED (RPH                           | 14.<br>3 75394.                |                 |
| MEAH DIA (IN) 0.81<br>ETF AREA (IN2) 1.32                          | \$ SPEED   | 3848.                          |                 |
|  | HEAD (FT<br>Dia. (IH                               | ) 2693.<br>) 1.53              |                 |
| MAX TIP SPEED 404.<br>STAGES 1                                     | TIP SPEED<br>VOL. FLON                             | 439.                           |                 |
| GAMMA 1.35 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01           | HEAD COST  | 228.<br>0.450                  |                 |
| PRESS RATIO (1/3) 1.01   | FLON COEF  | 4.201                          |                 |
| HORSEPOWER 12  |  |                                |                 |
| SPECIFIC SPEED 150.00  |  |                                |                 |
| SPECIFIC DIAMETER 0.48   |  |                                |                 |
| *****  |  |                                |                 |
| * H2 TURBINE *   | * H2 PU  |                                |                 |
| *********  |  |                                |                 |
|  | ******   | ME STAGE THO                   | *********       |
| EFFICIENCY (T/T) 0.797<br>EFFICIENCY (T/S) 0.779                   | HORSEPONER 500                                     | 3 8.583<br>. 481               | 0.589           |
| SPEED (RPH) 187500.  | SPEED (RPN) 187508                                 | 3 8.583<br>- 481.<br>- 187500. | 457.<br>187508. |
| HORSEPOMER 1447,<br>MEAN DIA. (IN) 1.77<br>EFF AREA (IN2) 0.12     | SPEED (RPN) 187508<br>SS SPEED 9319<br>S SPEED 664 | . <b>48</b> 7,                 | 786             |
|  | HEAD (FT) 71821.                                   | 69071.                         | 64271.          |
| HAN TIP SPEED 1565.  | DIA. (IN) 2.59<br>TIP SPEED 2091.                  | 2.55                           | 2092.           |
| U/C (ACTUAL) 0.511 MAN TIP SPEED 1545. STAGES 3 GAMMA 1.35         | VOL. FLON 242. HEAD COEF 8.526 FLON COEF 8.087     |                                | 241.<br>0.407   |
| **************************************                             | FLOW COSF 8.087                                    | )                              | V.447           |
| EXIT MACH HUMBER 0.13<br>SPECIFIC SPEED 49.66                      | DIAMETER RATIO 9.286<br>BEARING DH 3.86E+06        |                                |                 |
| SPECIFIC SPEED 49.66 SPECIFIC DIAMETER 1.46                        | SHAFT DIMETER 16.00                                |                                |                 |
|  |  |                                |                 |
| ***************  | ********   | *****                          |                 |
| * 02 BOOST TURBING H   | * 02 BOOST   |                                |                 |
|  |  |                                |                 |
| EFFICIENCY (T/T) 0.800<br>EFFICIENCY (T/S) 0.633                   | EFF1C1ENCY<br>HORSEPONER                           | 0.764<br>0.                    |                 |
| SPEED (RPH) 20184.   | SPEED (RPH)  | 20104.                         |                 |
|  | 3 SPEED<br>HEAD (FT)                               | 3826.<br>242.                  |                 |
| MVC (ACTUAL) 8.553<br>MAX TIP SPEED 243.                           | HEAD (FT)<br>DIA, (IN)<br>TIP SPEED                | 1.49                           |                 |
| STAGES 1   | VOL. FLON  | 132.<br>85.                    |                 |
| PRESS RATIO (T/T) 1.00 PRESS RATIO (T/S) 1.00                      | HEAD COEF<br>FLOH COEF                             | 0.450<br>0.206                 |                 |
| NORSEPONER #   |  |                                |                 |
| EXIT MACH NUMBER 0.03 SPECIFIC SPEED 100.41 SPECIFIC DIAMETER 0.76 |  |                                |                 |
| SPECIFIC DIAMETER 0.76   |  |                                |                 |
|  |  |                                |                 |
| * 02 TURBINE *   | *******  |                                |                 |
| **********   | P 02 PUMP  |                                |                 |
| EFFICIENCY (T/T) 0.808   | EFF IC LENCY                                       | 0.765                          |                 |
| EFFICIENCY (1/5) 0.749<br>SPEED (RPH) 132977.                      | HORSEPONER   | 210.                           |                 |
| HERSERGHER 110   | SPEED (RPH)<br>SS SPEED<br>S SPEED                 | 132977.<br>23899.              |                 |
| MEAN DIA (IN) 1.77<br>EFF AREA (IN2) 0.21<br>U/C (ACTUAL) 8.549    |  | 1777.                          |                 |
| U/C (ACTUAL) 8.549   | HEAD (FT)<br>DIA. (1H)                             | 6055.<br>1.19                  |                 |
| STAGES 1   | TIP SPEED<br>VOL. FLOW                             | 689,<br>84.                    |                 |
| GAPPA 1.35<br>PRESS RATIO (T/T) 1.08                               | HEAD COEF  | 0.411                          |                 |
|  | FLON COEF<br>DIAMETER RATIO                        | 0.152<br>0.679                 |                 |
| EXIT MACH HUMBER 0.09<br>SPECIFIC SPEED 52.85                      |  | 1.60E-06                       |                 |
| SPECIFIC DIMETER 1.48  | and blackly  | 12.00                          |                 |
|  |  |                                |                 |
| REGENERATOR DATA   |  |                                |                 |
| COLD SIDE HOT SIDE   |  |                                |                 |
| DELT 221.44 -254.15  |  |                                |                 |
| AREA 0.16 0.65<br>FLON 2.23 2.23                                   |  |                                |                 |
| EFFECTIVENESS 0.29   |  |                                |                 |
| MTU 0.41<br>CRATIO 0.87  |  |                                |                 |
| CHIN 7.85  |  |                                |                 |
| REGEN 0 1995.14  |  |                                |                 |

# TABLE 25. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 15,000 LBF THRUST (COPPER TUBE CHAMBER)

| ENGINE | PERFORMANCE | PARAMETERS |
|--------|-------------|------------|
|        |             |            |

| CHAMBER PRESSURE       | 1844.7 |
|------------------------|--------|
| VAC ENGINE THRUST      | 15000. |
| TOTAL ENGINE FLON RATE | 31.25  |
| DEL. VAC. ISP          | 480.1  |
| THROAT AREA            | 3.98   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 71.18  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA CO                 | 0.993  |
| CHAMBER COOLANT DP     | 901.   |
| CHAMBER COOLANT DT     | 599.   |
| MOZZI E CHANBER O      | 9975.  |

| BREEBERSSEESARSSEESARSEESARSEESEESEESEESEESEESEESEESEESEESEESEESEE |                            |                         |               |                  |                  |
|--|----------------------------|-------------------------|---------------|------------------|------------------|
|  |                            |                         |               |                  |                  |
|  | * FUEL                     | SYSTEM CO               | # ZMOITIONS # |                  |                  |
| STATION  | PRESS                      |                         | FLOH          | ENTHALPY         |                  |
| B.P. INLET   | 18.6                       | 37.4                    | 4.47          | -107.5           | 4.37             |
| D D EVIT   | 100.8                      | 38.5                    | 4.47          | -103.0           | 4.39             |
| PUMP INLET   | 100.8                      | 38.5                    | 4.47          | -103.0           | 4.39             |
| IST STAGE EXIT   | 2021.3                     | 68.9                    | 4.47          | 26.5             | 4.33             |
| 2ND STAGE EXIT   | 3897.6                     | 97.5                    | 4.47          | 152.4            | 4.35             |
| PUMP EXIT  | 5744.8                     | 124.4                   | 4.47          | 274.9            | 4.40<br>4.38     |
| COLD REGEN IN  | 5687.3<br>5630.4<br>5630.4 | 124.8                   | 4.47          | 274.9            | 2.60             |
| COLD REGEN EX  | 5630.4                     | 288.0<br>288.0<br>887.5 | 4.47          | 902.1<br>902.1   | 2.60             |
|  | 5630.4                     | 288.0                   | 4.47          | 3134.4           | 0.89             |
|  | 4729.4<br>4682.1           | 887.8                   | 0.22          | 3134.4           | 0.88             |
|  | 2128.1                     | 905.0                   | 0.22          | 3134.4           | 0.42             |
|  |                            |                         | 4.24          | 3134.4           | 0.88             |
| OZ TRB EXIT  | 4682.1<br>4278.6           | 887.8<br>872.5<br>872.5 | 4.24          | 3070.6           | 0.82             |
| H2 TRB INLET   | 4278.6                     | 872.5                   | 4.24          | 3076.6           | 0.82             |
|  | 2258.7                     | 773.5                   | 4.24          | 2672.8           | 0.51             |
| H2 TRB DIFFUSER  | 2226.4                     | 773.7                   | 4.24          | 2672.8           | 0.51             |
| H2 BST TRB IN  | 2204.1                     | 773.7                   | 4.24          | 2672.8           | 0.51             |
| H2 BST TRB OUT<br>H2 BST TRB DIFF                                  | 2185.4                     | 772.6                   | 4.24          | 2668.0           | 0.50             |
| H2 BST TRB DIFF  | 2170.8                     | 772.7                   | 4.24          | 2668.0           | 0.50             |
|  | 2149.1                     | 772.8                   | 4.24          | 2668.0           | 0.49             |
| D2 BST TRB OUT   | 2140.3                     | 772.2                   | 4.24          | 2665.4           | 0.49             |
| 02 BST TRB DIFF  | 2138.8                     | 772.2                   | 4.24          | 2665.4           | 0.0044           |
| HZ TANK PRESS  | 18.6                       |                         | 0.0045        | 2688.9<br>2688.9 | 0.48             |
| GOX HEAT EXCH IN   | 2128.1                     | 778.9<br>778.6          | 4.46          | 2687.5           | 0.48             |
| GOX HEAT EXCH OUT  | 2117.5                     | 778.6                   | 4.46          | 2687.5           | 0.48             |
|  | 2117.5<br>2054.0           | 601.9                   | 4.46          | 2059.7           | 0.60             |
|  | 2054.0                     | 601.9                   | 4.46          | 2059.7           | 0.60             |
| FSOV INLET   | 2002.6                     | 602.1                   | 4.46          | 2059.7           | 0.58             |
| FSOV EXIT<br>CHAMBER INJ   | 1982.7                     | 602.2                   | 4.46          |                  | 0.58             |
| CHAMBER  | 1844.7                     |                         |               |                  |                  |
| G P D L .  | •                          |                         |               |                  |                  |
|  |                            |                         |               |                  |                  |
|  | * OXYY                     | EN SYSTEM               | CONDITION     | S                | DC1401714        |
| STATION  | PRESS                      | TEMP                    | FLOH          | ENTHALPY         | DENSITY<br>71.17 |
| B.P. INLET   | 16.0                       | 162.7                   | Z6.8          | 61.1             | 71.20            |
| B.P. EXIT  | 135.6                      | 163.2                   | 26.8          | 61.5             | 71.20            |
| PUMP INLET   | 135.6                      | 163.2                   | 26.8<br>26.8  | 71.6             | 71.67            |
| PUMP EXIT<br>OZ TANK PRESS   | 2987.5                     | 177.0<br>400.0          | 0.045         | 204.7            | 0.12             |
| OZ TANK PRESS  | 16.0                       | 177.2                   | 26.8          | 71.6             | 71.62            |
| OCV INLET  | 2957.7<br>2070.4           | 180.6                   |               | 71.6             | 70.25            |
| OCV EXIT<br>CHAMBER INJ  | 2029.2                     | 180.8                   |               | 71.6             |                  |
| CHAMBER  | 1844.7                     |                         |               |                  |                  |
| CHARDER  |                            |                         |               |                  |                  |
|  |                            |                         |               |                  |                  |
|  | 1                          | VALVE D                 | ATA =         |                  |                  |
| VALVE  | DELTA P                    | AREA                    | FLON          | % BYPASS         |                  |
| TBV  | 2554.                      | 0.01                    | 0.22          | 5.00             |                  |
| FSOV   | 51.                        | 1.18                    | 4.46          |                  |                  |
| DCV  | 887.                       | 0.16                    | 26.78         |                  |                  |
|  |                            |                         |               |                  |                  |
|  |                            | INJECTOR                | DATA P        |                  |                  |
| INJECTOR   |                            |                         | FLOM          | VELOCITY         |                  |
|  | 138.                       |                         |               | 1770 61          |                  |
| FUEL<br>LOX  | 205.                       | 0.35                    | 26.78         | 156.04           |                  |
| LUA  | 2.53.                      |                         |               |                  |                  |

TABLE 25. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 15,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

\*

|   | INERY PERFORMANCE DA          |  |                          |              |
|---|-------------------------------|--|--------------------------|--------------|
| ********  |                               | ****                                   |                          |              |
| *************   |                               | ********                               |                          |              |
| H2 BOOST TURBINE #  |                               | 2 BOOST PL                             |                          |              |
|   |                               |  |                          |              |
| EFFICIENCY (T/T) 0.736<br>EFFICIENCY (T/S) 0.359  | HORSE                         | ENCY OMER (RPH) D (FT) (JH) EED        | 29.                      |              |
| SPEED (RPM) 53374.  | SPEED                         | (8211)                                 | 53374.                   |              |
| MEAN DIA (1N) 1.16<br>EFF AREA (1N2) 2.02   | S SPEE                        | D<br>(FT)                              | 3045.<br>2700.           |              |
| MEAN DIA (IN) 1.16<br>EFF AREA (IN2) 2.02<br>U/C (ACTUAL) 0.553   | DIA.                          | (1H)                                   | 1.89                     |              |
| MAX TIP SPEED 397.<br>STAGES 1  | TIP SP                        | EED                                    | 439.<br>457              |              |
| GAPA 1.41   | HEAD C                        | L.0ni<br>069<br>069                    | 457.<br>0.450<br>0.201   |              |
| GAPPIA 1.41 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02   | FLOM C                        | ŒF                                     | 0.201                    |              |
| HORSEPOHER 29.  |                               |  |                          |              |
| HORSEPOHER 29. EXIT MACH NUMBER 0.10 SPECIFIC SPEED 147.58  |                               |  |                          |              |
| SPECIFIC DIAMETER 0.51  |                               |  |                          |              |
| ***********   |                               |  |                          |              |
| # H2 TURBINE #  |                               | - 12 PUP                               |                          |              |
| **********  |                               | ************************************** |                          | STAGE THREE  |
|   |                               | *******                                | ********                 | *********    |
| EFFICIENCY (T/T) 0.794  | EFF1C1ENCY<br>HORSEPONET      | 0.631                                  | 0.635<br>797             | 0.637<br>774 |
| SPEED (RPH) 136363.   | SPEED (RPH)                   | 134343.                                | 136363.                  | 134343.      |
| HORSEPONER 2389.  | SS SPEED                      | 9568.                                  | 74 2                     | 74.7         |
| EFF AREA (IN2) 0.21   | HEAD (FT)                     | 435 <b>8</b> 2.                        | 62239.                   | 60761.       |
| U/C (ACTUAL) 0.464  | DIA. (IN)                     | 8.27                                   | 3.27                     | 3.27         |
| MAX TIP SPEED 1560.<br>STAGES 2   | TIP SPEED<br>VOL. FLOW        | 463.                                   | 1747.<br>461.            | 455.         |
| EFFICIENCY (T/T) 0.794 EFFICIENCY (T/S) 0.773 SPEED (RPH) 136363. HORSEPOMER 2389. HEAN DIA. (IN) 2.46 EFF AREA (IN2) 0.21 U/C (ACTUAL) 0.464 HAX TIP SPEED 1560. STAGES 2 GAMMA 1.61 PRESS RATIO (T/T) 1.89 PRESS RATIO (T/S) 1.93 EXIT MACH NUMBER 0.14 SPECIFIC SPEED 36.41 SPECIFIC DIAMETER 1.69 | HEAD COEF                     | 0.539                                  | 0.527                    | 0.515        |
| PRESS RATIO (T/T) 1.89 PRESS RATIO (T/S) 1.93   | FLON COEF<br>DIAMETER RATIO   | 0.092<br>0.315                         |                          |              |
| EXIT MACH NUMBER 0.14   | BEARING IN                    | 3.00€ • 06                             |                          |              |
| SPECIFIC SPEED 38.41<br>SPECIFIC DIAMETER 1.69  | SHAFT DIAMETER                | 22.00                                  |                          |              |
|   |                               |  |                          |              |
| *************   |                               |  |                          |              |
| * D2 BOOST TURBINE #  |                               | 2 BOOST PU                             |                          |              |
|   |                               |  |                          |              |
| EFF1C1ENCY (T/T) 0.824<br>EFF1C1ENCY (T/S) 0.674  | EF ICII                       | ENCY<br>OMER<br>(SPH)                  | 8.764                    |              |
| SPEED (RPH) 14272.  | SPEED                         | (RPH)                                  | 14272.                   |              |
| SPEED (RPH) 14272.<br>MEAN DIA (IH) 3.18<br>EFF AREA (IM2) 2.97   | S SPEE                        | D (87)                                 | 3826.<br>242.            |              |
| U/C (ACTUAL) 0.553  | DIA.                          | (FT)<br>(TH)                           | 2.11                     |              |
| MAX TIP SPEED 237.<br>STAGES 1  | TIP SPI                       | EEB)                                   | 2.11<br>132.<br>169.     |              |
| STAGES 1 GAMMA 1.41   | YOL, FI<br>HEAD CI<br>FLON CI | OEF                                    | 0.450                    |              |
| PRESS RATIO (T/T) 1.00  | PLOM C                        | ŒF                                     | 0.200                    |              |
| GAMMA 1.41 PRESS RATIO (T/T) 1.00 PRESS RATIO (T/S) 1.01 HORSEPOMER 15.   |                               |  |                          |              |
| HORSEPOHER 15. EXIT MACH NUMBER 8.03 SPECIFIC SPEED 101.42  |                               |  |                          |              |
| SPECIFIC DIAMETER 0.82  |                               |  |                          |              |
|   |                               |  |                          |              |
|   |                               | 02 PUP +                               |                          |              |
| OZ TURBINE P  |                               |  |                          |              |
| EFFICIENCY (T/T) 0 800  | pprici                        | BICY                                   | 0.729                    |              |
| EFFICIENCY (T/T) 0.820<br>EFFICIENCY (T/S) 0.767  | HORSEM                        | ENCY<br>ENER<br>(RPH)                  | 578 3 .                  |              |
| SPEED (RPM) 91028.  | SPEED                         | (RPH)<br>ED                            | 91 <b>020.</b><br>23136. |              |
| HORSEPOHER 383.<br>HEAN DIA (IN) 2.46   | S SPEEI                       | D                                      | 1792.                    |              |
| EFF AREA (1H2) 0.33   | HEAD                          | (FT)<br>(IN)                           | 5729.                    |              |
| U/C (ACTUAL) 0.547<br>MAX TIP SPEED 1043.   | DIA.<br>Tip SPI               |  | 1.67<br>663.             |              |
| STAGES 1  | VOL. FL                       | .CM                                    | 148.                     |              |
| GAPPIA 1.41 PRESS RATIO (T/T) 1.09  | HEAD CI<br>FLON CI            |  | 0.420<br>0.153           |              |
| PRESS BATTO (T/S) 1.16  | DIAMETT                       | ER RATIO                               | 0.686                    |              |
| EXIT MACH NUMBER 0.09<br>SPECIFIC SPEED 48.17   |                               | S DN<br>DIAMETER                       | 1.46E+06<br>16.00        |              |
| SPECIFIC DIAMETER 1.63  |                               |  |                          |              |
|   |                               |  |                          |              |
| REGENERATOR   |                               |  |                          |              |
| COLD SIDE HOT   | SIDE                          |  |                          |              |
|   | 63.52<br>76.69                |  |                          |              |
| AREA 0.30   | 1.19                          |  |                          |              |
| FLON 4.47 EFFECTIVENESS 0.27  | 4.46                          |  |                          |              |
| NTU 0.38  |                               |  |                          |              |
| CRATIO 0.92<br>CHIN 15.86   |                               |  |                          |              |
| REGEN Q 2802.44   |                               |  |                          |              |
|   |                               |  |                          |              |

# TABLE 26. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 25,000 LBF THRUST (COPPER TUBE CHAMBER)

| ENGINE    | PERFORMANCE | PARAMETERS  |
|-----------|-------------|-------------|
| ********* | *********   | *********** |

| CHAMBER PRESSURE       | 1786.4 |
|------------------------|--------|
| VAC ENGINE THRUST      | 25000. |
| TOTAL ENGINE FLON RATE | 52.08  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 6.85   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 93.38  |
| ENGINE HIXTURE RATIO   | 6.00   |
| ETA C*                 | 0.993  |
| CHAMBER COOLANT DP     | 831.   |
| CHAMBER COOLANT DT     | 480.   |
| NOZZLE/CHAMBER Q       | 13641. |

| 计自由 化甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基甲基 |                  |                |              |                  |              |
|---|------------------|----------------|--------------|------------------|--------------|
|   | e FIET           | SYSTEM CON     | nitions =    |                  |              |
| STATION                                     | PRESS            | TEMP           | FLOH         | ENTHALPY         | DENSITY      |
| B.P. INLET                                  | 18.6             | 37.4           | 7.45         | -107.5           | 4.37         |
| B.P. EXIT                                   | 101.2            | 38.5           | 7.45         | -103.0           | 4.39         |
| PUMP INLET                                  | 101.2            | 38.5           | 7.45         | -103.0           | 4.39         |
|   | 1817.1           | 60.7           | 7.45         | -1.1             | 4.48         |
|   | 3543.3           | 81.9           | 7.45         | 100.0            | 4.56         |
| PUMP EXIT                                   | 5281.9           | 102.4          | 7.45         | 200.0            | 4.64         |
| COLD REGEN IN                               | 5229.1           | 102.9          | 7.45         | 200.0            | 4.62         |
| COLD REGEN EX                               | 5176.8           | 253.0          | 7.45         | 745.0            | 2.71<br>2.71 |
| COOLANT INLET                               | 5176.8           | 253.0          | 7.45         | 745.0            | 0.98         |
| COOLANT EXIT                                | 4346.0           | 733.1          | 7.45         | 2576.3<br>2576.3 | 0.97         |
| TBV INLET                                   | 4302.6           | 733.4          | 0.37<br>0.37 | 2576.3           | 0.49         |
| TBV EXIT                                    | 2062.2           | 747.5<br>733.4 | 7.08         | 2576.3           | 0.97         |
| 02 TRB INLET                                | 4302.6           | 719.1          | 7.08         | 2516.2           | 0.91         |
| 02 TRB EXIT                                 | 3897.1<br>3897.1 | 719.1          | 7.08         | 2516.2           | 0.91         |
|   | 2196.4           | 639.3          | 7.08         | 2197.4           | 0.60         |
| H2 TRB EXIT                                 | 2159.5           | 639.5          | 7.08         | 2197.4           | 0.59         |
|   | 2137.9           | 639.5          | 7.08         | 2197.4           | 0.59         |
|   | 2118.2           | 638.4          | 7.08         | 2192.6           | 0.58         |
|   | 2104.8           | 638.4          | 7.08         | 2192.6           | 0.58         |
| OZ BST TRB IN                               | 2083.8           | 638.6          | 7.08         | 2192.6           | 0.57         |
|   |                  | 637.9          | 7.08         | 2190.0           | 0.57         |
| 02 BST TRB OUT<br>02 BST TRB DIFF           | 2072.6           | 637.9          | 7.08         | 2190.0           | 0.57         |
| H2 TANK PRESS                               | 18.6             | 654.5          | 0.0091       | 2209.4           | 0.0053       |
| GOX HEAT EXCH IN                            | 2062.2           | 643.4          | 7.44         | 2209.4           | 0.56         |
| GOX HEAT EXCH OUT                           |                  | 643.1          | 7.44         | 2208.0           | 0.56         |
| HOT REGEN IN                                | 2051.9           | 643.1          | 7.44         | 2208.0           | 0.56         |
| HOT REGEN EX                                | 1990.4           | 493.1          | 7.44         | 1662.4           | 0.70<br>0.70 |
| FSOV INLET                                  | 1990.4           | 493.1          | 7.44         | 1662.4<br>1662.4 | 0.48         |
| FSOV EXIT                                   | 1940.6           | 493.3          | 7.44         | 1662.4           | 0.68         |
| CHAMBER INJ                                 | 1921.0           | 493.3          | 7.44         | 1002.4           | *            |
| CHAMBER                                     | 1786.4           |                |              |                  |              |
|   |                  |                |              |                  |              |
|   |                  | GEN SYSTEM     |              |                  | DENSITY      |
| STATION                                     | PRESS            |                | FLOH<br>44.7 | 61.1             | 71.17        |
| B.P. INLET                                  | 16.0             | 162.7          | 44.7         | 61.5             | 71.20        |
| B.P. EXIT                                   | 135.6            | 163.2<br>163.2 | 44.7         | 61.5             | 71.20        |
| PUMP INLET                                  | 135.6<br>2893.0  |                | 44.7         | 71.0             | 71.75        |
| PUMP EXIT  02 TANK PRESS  0CV INLET         | 2893.0           | 400.0          | 0.076        | 204.7            | 0.12         |
| DZ TANK PRESS                               | 2044 1           | 176.1          | 44.6         | 71.0             | 71.70        |
| OCV INLET                                   | 2004.9           | 179.4          | 44.6         | 71.0             | 70.37        |
| OCV EXIT                                    | 1965.0           | 179.6          | 44.6         | 71.0             | 70.31        |
| CHAMBER INS                                 | 1786.4           | ••••           |              |                  |              |
| CHANDEN                                     |                  |                |              |                  |              |
|   |                  |                |              |                  |              |
|   | DELTA P          | P VALVE DA     | TLOH         | % BYPASS         |              |
| VALVE                                       | 2240.            |                | 0.37         | 5.00             |              |
| TBV   | 50.              |                | 7.44         |                  |              |
| FSDV<br>OCV                                 | 859.             |                |              |                  |              |
| UC <b>V</b>                                 | <b>U</b> 2/.     |                |              |                  |              |
|   |                  |                | DATA B       |                  |              |
|   |                  | INJECTOR       | DATA =       | VELOCITY         |              |
| INJECTOR                                    | DELTA P          |                | FLOH<br>7.44 | 1266.91          |              |
| FUEL  | 135.             |                |              | 153.42           |              |
| FOX   | 198.             | 0.60           | ****         | .55.46           |              |

TABLE 26. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 25,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| * TURBONACHINE  | ERV PERFORMANCE DATA =  |               |
|---|---|---------------|
| # H2 BOOST TURBINE #  | ***************************************   |               |
| **************************************                                      | P H2 BOOST PURP +   |               |
|   |   |               |
| EFFICIENCY (T/T) 0.823<br>EFFICIENCY (T/S) 0.431                            | EFFICIENCY 0.745<br>HORSEPONER 48.  |               |
| SPEED (RPH) 41428.  | SPEED (RPH) 41428.  |               |
| MEAN DIA (IN) 1.44<br>EFF AREA (IN2) 3.02                                   | S SPEED 3041.   |               |
| U/C (ACTUAL) 0.538  | HEAD (FT) 2713.   |               |
| MAX TIP SPEED 377.  | DIA. (IN) 2.43<br>TIP SPEED 440.  |               |
| STAGES  | VOL. FLON 762.  |               |
| CAMMA 1.44 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02                    | HEAD COEF 0.450<br>FLOW COEF 0.208  |               |
| PRESS RATIO (T/S) 1.02  | 7.200 U.200   |               |
|   |   |               |
| EXIT HACH NUMBER 0.10<br>SPECIFIC SPEED 150.00                              |   |               |
| SPECIFIC DIAMETER 0.52  |   |               |
|   |   |               |
| **********  | **********  |               |
| # HZ TURBINE #  | * H2 PUMP *   |               |
| 4*********  | *****   |               |
|   | STAGE ONE STAGE THO S   |               |
| EFF1C1ENCY (T/T) 0.856<br>EFF1C1ENCY (T/S) 0.826                            | EFFICIDICY 8.700 8.699  | 0.699         |
| EFF1C1ENCY (T/S) 0.826<br>SPEED (RPH) 125000.                               | EFFICIENCY 8.700 8.699<br>HORSEPONER 1073, 1064,<br>SPEED (APM) 125000, 125000, | 1054.         |
| HORSEPONER 3191.  | SPEED (APH) 125000. 125000.<br>SS SPEED 11287.                                  | 125000.       |
| HORSEPONER 3191. HEAN DIA. (IN) 2.61 EFF AREA (IN2) 0.35 HAG (ACTION) 0.505 | S SPEED 945. 943.   | 942.          |
| EFF AREA (1H2) 0.35   | HEAD (FT) 55475. 54951.   | 54386.        |
|   | DIA. (IN) 3.38 3.38<br>TIP SPEED 1045, 1045,                                    | 3.30<br>1944. |
| STAGES 2  | VOL. FLOM 746. 733.   | 720.          |
| GAMMA 1,44  | HEAD COEF 0.524 8.519   | 0.514         |
| PRESS RATIO (T/T) 1.77 PRESS RATIO (T/S) 1.81                               | FLOW COEF 0.107<br>DIAMETER RATIO 0.373   |               |
| EXIT MACH NUMBER 0.16   | BEARING DN 3.00E+06   |               |
| SPECIFIC SPEED 51.88<br>SPECIFIC DIAMETER 1.43                              | SHAFT DIAMETER 24.00  |               |
| Seem to Bracelon 1.43   |   |               |
| • 02 BOOST TURBINE •  | • C2 BCOST PUMP •   |               |
| EFF1C1ENCY (T/T) 0.877  | EFFICIENCY 8.764  |               |
| EFFICIENCY (T/\$) 0.729   | HORSEPOHER 26.  |               |
| SPEED (RPH) 11055.<br>MEAN DIA (IN) 4,11                                    | SPEED (RPH) 11055.<br>S SPEED 3026.   |               |
| EFF AREA (IN2) 4.35   | HEAD (FT) 242.<br>DIA. (IN) 2.72  |               |
| NAC (ACTUAL) 0.553  | DIA. (IN) 2.72  |               |
| MAX TIP SPEED 234.<br>STAGES 1  | TIP SPEED 132.<br>VOL. FLON 282.  |               |
| GAPPIA 1.44   | HEAD COEF 0.450<br>FLOW COEF 0.200  |               |
| PRESS RATIO (T/T) 1.00<br>PRESS RATIO (T/S) 1.01                            | FLOH COEF 8.200   |               |
| HORSEPOHER 24.  |   |               |
| EXIT MACH HUNDER 0.03<br>SPECIFIC SPEED 99.31                               |   |               |
| SPECIFIC SPEED 99.31<br>SPECIFIC DIAMETER 0.86                              |   |               |
| SECURIC DINCELER 8.85   |   |               |
| FREEFENDORDES<br>P 02 TURBINE 4   | **************************************  |               |
| ***********   | **********  |               |
| EFFICIENCY (T/T) 0.854  | EFFICIENCY 0.747  |               |
| EFFICIENCY (T/S) 0.794 SPEED (RPH) 69046.                                   | HORSEPOMEN 602.<br>SPEED (RPH) 69846.   |               |
|   | 33 SPEED 22656.   |               |
| MEAN DIA (IN) 2.61  |   |               |
| EFF AREA (IN2) 8.53<br>U/C (ACTUAL) 8.654                                   | MEAD (FT) 5532.<br>DIA. (IN) 2.14   |               |
| MAX TIP SPEED 855.  | TIP SPEED 646.  |               |
| STAGES )  | VOL. FLON 280.  |               |
| GAMMA 3.44 PRESS RATIO (T/T) 3.10   | HEAD COEF 0.426<br>FLOW COEF 0.153  |               |
| BRESS SATIR (T/S) 1 11  | FLOW COEF 0.153<br>DIAMETER RATIO 0.681   |               |
| EXIT MACH HUMBER 0.09   | BEARING DN 1.38E+06   |               |
| SPECIFIC SPEED 48.09  | SHAFT DIAMETER 20:00  |               |
| SPECIFIC DIAMETER 1.48  |   |               |
| REGENERATOR DATA  |   |               |
| COLD SIDE HOT SIDE  |   |               |
| DELP 52.29 61.56  |   |               |
| DELT 150.12 -150.00<br>AREA 0.50 1.86                                       |   |               |
| FLOM 7.45 7.44  |   |               |
| EFFECTIVENESS 0.28 NTU 0.40   |   |               |
| NTU 0.40<br>CRATID 1.00   |   |               |
| CHIN 27.04  |   |               |
| REGEN 9 4059.52   |   |               |
|   |   |               |

TABLE 27. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR
— 37,500 LBF THRUST (COPPER TUBE CHAMBER)

| ENGINE   | PERFORMANCE | PARAMETERS |
|----------|-------------|------------|
| ******** | ********    |            |

| CHAMBER PRESSURE       | . 1673.2 |
|------------------------|----------|
| VAC ENGINE THRUST      | 37500.   |
| TOTAL ENGINE FLOH RATE | 78.12    |
| DEL. VAC. ISP          | 480.0    |
| THROAT AREA            | 10.96    |
| NOZZLE AREA RATIO      | 1000.0   |
| NOZZLE EXIT DIAMETER   | 118.14   |
| ENGINE MIXTURE RATIO   | 6.00     |
| ETA C.                 | 0.993    |
| CHAMBER COOLANT DP     | 752.     |
| CHAMBER COOLANT DT     | 403.     |
| NOZZI E / CHAMBER O    | 17580.   |

|  | e FUEL  | SYSTEM CON     | DITIONS *      |                  |              |
|--|---------|----------------|----------------|------------------|--------------|
| STATION  | PRESS   | TEMP           | FLOH           | ENTHALPY         | DENSITY      |
| B.P. INLET   | 18.6    | 37.4           | 11.18          | -107.5           | 4.37         |
| B.P. EXIT  | 100.8   | 38.5           | 11.18          | -103.0           | 4.39         |
| PUMP INLET   | 100.8   | 38.5           | 11.18          | -103.0           | 4.39         |
|  | 1768.9  | 58.6           | 11.18          | -7.9             | 4.52         |
|  | 3463.0  | 77.9           | 11.18          | 87.1             | 4.62         |
| PUMP EXIT  | 5182.8  | 96.7<br>97.2   | 11.18          | 181.6            | 4.72         |
| COLD REGEN IN                                      | 5130.9  | 97.2           | 11.18          | 181.4            | 4.70         |
| COLD REGEN EX                                      | 5079.6  | 228.0          | 11.18          | 638.8            | 2.90         |
| COOLANT INLET                                      | 5079.6  | 228.0          | 11.18          | 638.8            | 2.90<br>1.11 |
|  | 4327.2  | 630.5          | 11.18          | 2211.8           | 1.11         |
|  | 4283.9  | 630.8          | 0.56           | 2211.8<br>2211.8 | 0.53         |
|  | 1930.3  | 644.8          | 0.56           | 2211.8           | 1.10         |
|  | 4283.9  | 630.B          | 10.62<br>10.62 | 2156.7           | 1.03         |
|  | 3867.8  | 618.4<br>618.4 | 10.62          | 2156.7           | 1.03         |
|  | 3867.8  | 546.1          | 10.62          | 1857.1           | 0.66         |
|  | 2072.2  | 546.3          | 10.62          | 1857.1           | 0.64         |
| H2 TRB DIFFUSER                                    | 2026.3  | 546.3          | 10.62          | 1857.1           | 0.64         |
| ,  | 1984.9  | 545.1          | 10.62          | 1852.3           | 0.63         |
| H2 BST TRB DIFF                                    |         | 545.2          | 10.62          | 1852.3           | 0.63         |
|  |         | 545.3          |                | 1852.3           | 0.62         |
| 02 BST TRB IN<br>02 BST TRB OUT<br>02 BST TRB DIFF | 1961.5  | 544.6          | 10.62          | 1849.7           | 0.62         |
| OZ BST TOR DIFF                                    | 1940.0  | 544.6          | 10.62          | 1849.7           | 0.62         |
| H2 TANK PRESS                                      | 18.6    | 558.1          | 0.0161         | 1867.8           | 0.0063       |
| GOX HEAT EXCH IN                                   |         | 549.7          | 11.16          | 1867.8           | 0.61         |
| GOX HEAT EXCH OUT                                  |         | 549.3          | 11.16          | 1866.5           | 0.61         |
|  |         | 549.3          | 11.16          | 1866.5           | 0.61         |
| HOT REGEN IN<br>HOT REGEN EX                       | 1863.0  | 425.3          | 11.16          | 1408.6           | 0.75         |
|  | 1863.0  | 425.3          | 11.16          | 1408.6           | 0.75         |
|  | 1816.4  | 425.4          | 11.16          | 1408.6           | 0.74         |
| FSOV EXIT CHAMBER INJ CHAMBER                      | 1798.4  | 425.5          | 11.16          | 1408.6           | 0.73         |
| CHAMBER  | 1673.2  |                |                |                  |              |
|  |         |                |                |                  |              |
|  | - 000   | GEN SYSTEM     | COMBITION      | s =              |              |
| STATION  | PRESS   | TEMP           | FLOH           | ENTHALPY         | DENSITY      |
| B.P. INLET   | 16.0    | 162.7          | 67.1           | 61.1             | 71.17        |
| B.P. EXIT  | 135.6   | 163.2          | 67.1           | 61.5             | 71.20        |
| PUMP INLET   | 135.6   | 163.2          | 67.1           | 61.5             | 71.20        |
|  | 2709.7  | 174.B          | 67.1           | 70.2             | 71.77        |
| D2 TANK PRESS                                      |         |                | 0.113          | 204.7            | 0.12         |
|  | 2682.6  |                | 67.0           | 70.2             | 71.73        |
| OCV EXIT   | 1877.8  | 177.9          | 67.0           | 70.2             | 70.48        |
|  | 1840.5  |                | 67.0           | 70.2             | 70.42        |
| CHAMBER  | 1673.2  |                |                |                  |              |
|  |         |                |                |                  |              |
|  |         | = VALVE DA     | TA .           |                  |              |
| 14A1 14E   | DELTA P | AREA           |                | * BYPASS         |              |
|  | 2354.   |                | 0.56           | 5.00             |              |
| TBV  | 47.     |                | 11.16          | <del>-</del>     |              |
| FSOV<br>OCV  | 805.    |                |                |                  |              |
| OC 4   | 505.    | J              |                |                  |              |
|  |         | INJECTOR       | DATA -         |                  |              |
|  |         | AREA           |                | VELOCITY         |              |
|  | DELTA P |                |                |                  |              |
| FUEL.  | 125.    |                | 66.96          | 148.36           |              |
| LOX  | 100.    | V.,L           | •••••          |                  |              |

TABLE 27. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 37,500 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

| • TURBOHACHINE   | ERY PERFORMANCE DATA #  |
|--|---|
| * M2 BOOST TURBING #   | P H2 BOOST PUMP 4   |
| EFFICIDICY (T/T) 8.839 EFFICIDICY (T/S) 6.456 SPEED (89H) 33742. HEAN DIA (1H) 1.77 EFF AMEA (1M2) 4.19 U/C (ACTUAL) 8.533 HAX TIP SPEED 573. STAGES 1 GAMM 1.36 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02 HURSEPORER 72. EXIT MACH NUMBER 6.19 SPECIFIC SPEED 150.06 SPECIFIC DIAMETER 8.53  | EFFICIENCY 0.745 HORSEPONER 72. SPEED RPH) 33742. S. SPEED 3044. HEAD (FT) 2599. DIA. (1N) 2.90 TIP SPEED 439. VOL. FLOM 1143. HEAD COEF 0.450 FLOM COEF 0.291  |
| e M2 TURBINE =   | ERRECTIONS  1 NZ PUP 0 111111111111111111111111111111111111   |
| STAGES 2 GAMMA 1.36 PRESS RATIO (T/T) 1.87 PRESS RATIO (T/S) 1.92 EXIT MACH MUMBER 8.39  | ######################################  |
| DESCRIPTION OF THE PROPERTY OF | • 02 BOOST PURP •   |
| EFFICIENCY (T/T) 8.887 EFFICIENCY (T/S) 8.746 SPEED (RPM) 9026. HEAN DIA (IN) 5.06 EFF ANEA (INC) 6.553 NAX TIP SPEED 252. STAGES 1 GANNA 1.36 PRESS RATIO (T/T) 1.01 HORSEPOMER 39. EXIT MACH HUMBER 90.04 SPECIFIC SMEED 96.51 SPECIFIC DIAMETER 0.89  | EFFICIENCY 0.764 HORSEPONER 39. SPEED (RPH) 9626. S SPEED 3826. HEAD (FT) 242. DIA. (IN) 3.34 TIP SPEED 132, VOL. FLOW 423. HEAD CODE 0.458 FLOM CODEF 8.299  |
| + 02 TURBINE +   | липливалав<br>п 02 РИФ о<br>вления  |
| EFFICIENCY (7/T) 0.800 EFFICIENCY (7/S) 0.827 SPEED (RPH) 54516. HOSSPONER 028. HEAN DIA (IN) 2.72 EFF ARA (IN) 0.550 HAX TIP SPEED 726. STAGES 2 GAMMA 1.36 PRESS RATIO (T/T) 1.11 PRESS RATIO (T/T) 1.12 EXIT MON HUMBER 6.09 SPECIFIC SPEED 76.33 SPECIFIC DIAMETER 1.09  | EFFICIENCY 0.760 HORSEPOMER 020. SPEED 021910. SS SPEED 21910. SS SPEED 10333. HEAD (FT) 5162. DIA. (IN) 2.61 TIP SPEED 621. VOL. FLOM 419. HEAD CODF 0.431 FLOM CODF 0.431 FLOM CODF 0.495 DIAMETER RATIO 0.405 SMAFT DIAMETER 26.00 |
| REGENERATOR DAYA   |   |

# TABLE 28. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 50,000 LBF THRUST (COPPER TUBE CHAMBER)

#### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE       | 1557.9 |
|------------------------|--------|
| VAC ENGINE THRUST      | 50000. |
| TOTAL ENGINE FLON RATE | 104.17 |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 15.69  |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 141.34 |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C.                 | 0.993  |
| CHAMBER COOLANT DP     | 672.   |
| CHAMBER COOLANT DT     | 358.   |
| NOZZLE/CHAMBER Q       | 21099. |

| *************************************** |                  |   |                |                  |                  |
|---|------------------|---|----------------|------------------|------------------|
|   | * FUEL           | SYSTEM CO                               | NDITIONS .     |                  |                  |
| STATION                                 | PRESS            | TEMP                                    | FLOH           | ENTHALPY         | DENSITY          |
| B.P. INLET                              | 18.6             | 37.4                                    | 14.91          | -107.5           | 4.37             |
| B.P. EXIT                               | 100.9            | 38.5                                    | 14.91          | -103.0           | 4.39             |
| PUMP INLET                              | 100.9            | 38.5                                    | 14.91          | -103.0           | 4.39             |
| IST STAGE EXIT                          | 1612.6           | 55.5                                    | 14.91          | -20.1            | 4.55             |
| 2ND STAGE EXIT                          | 3160.0           | 71.8                                    | 14.91          | 63.0             | 4.66             |
| PUMP EXIT                               | 4741.5           | 87.7                                    | 14.91          | 146.2            | 4.77<br>4.75     |
| COLD REGEN IN                           | 4694.1           | 88.2                                    | 14.91          | 146.2<br>534.3   | 2.98             |
| COLD REGEN EX                           | 4647.1<br>4647.1 | 204.0<br>204.0                          | 14.91          | 534.3            | 2.98             |
| COOLANT INLET                           | 3975.6           | 561.9                                   | 14.91          | 1949.9           | 1.14             |
| COOLANT EXIT TBV INLET                  | 3935.8           | 562.1                                   | 0.75           | 1949.9           | 1.13             |
| TBV EXIT                                | 1797.6           | 572.8                                   | 0.75           | 1949.9           | 0.55             |
| OZ TRB INLET                            | 3935.8           | 562.1                                   | 14.16          | 1949.9           | 1.13             |
| 02 TRB EXIT                             | 3542.5           | 550.4                                   | 14.16          | 1899.3           | 1.06             |
| HZ TRB INLET                            | 3542.5           | 550.4                                   | 14.16          | 1899.3           | 1.06             |
| HZ TRB EXIT                             | 1937.7           | 486.3                                   | 14.16          | 1637.1           | 0.69             |
| H2 TRB DIFFUSER                         | 1891.0           | 486.5                                   | 14.16          | 1637.1           | 0.67             |
| H2 BST TRB IN                           | 1872.0           | 486.5                                   | 14.16          | 1637.1           | 0.67             |
| H2 BST TRB OUT                          | 1850.4           | 485.4                                   | 14.16          | 1632.3           | 0.66             |
| H2 BST TRB DIFF                         | 1837.4           | 485.4                                   | 14.16          | 1632.3           | 0.66             |
| O2 BST TRB IN                           | 1819.1           | 485.5                                   | 14.16          | 1632.3           | 0.65             |
| 02 BST TRB OUT                          | 1808.2           | 484.8                                   | 14.16          | 1629.8           | 0.65             |
| 02 BST TRB DIFF                         | 1806.7           | 484.8                                   | 14.16          | 1629.8           | 0.65             |
| H2 TANK PRESS                           | 18.6             | 495.7                                   | 0.0242         | 1645.8<br>1645.8 | 0.0071           |
| GOX HEAT EXCH IN                        |                  | 489.3                                   | 14.88<br>14.88 | 1644.4           | 0.64             |
| GOX HEAT EXCH OUT                       |                  | 488.9<br>488.9                          | 14.88          | 1644.4           | 0.64             |
| HOT REGEN IN                            | 1788.7<br>1735.0 | 386.3                                   | 14.88          | 1255.6           | 0.78             |
| HOT REGEN EX<br>FSOV INLET              | 1735.0           | 386.3                                   | 14.88          | 1255.6           | 0.78             |
| FSOV EXIT                               | 1691.6           | 386.4                                   | 14.88          | 1255.6           | 0.76             |
| CHAMBER INJ                             | 1675.1           | 386.4                                   | 14.88          | 1255.6           | 0.75             |
| CHAMBER                                 | 1557.9           |   |                |                  |                  |
|   |                  |   |                |                  |                  |
|   |                  |   |                |                  |                  |
|   |                  |   | CONDITION      |                  | NC. 10 1 TM      |
| STATION                                 | PRESS            | TEMP                                    | FLOH           | ENTHALPY         | DENSITY<br>71.17 |
| B.P. INLET                              | 16.0             | 162.7                                   | 89.4           | 61.1<br>61.5     | 71.20            |
| B.P. EXIT                               | 135.6            | 163.2                                   | 89.4           | 61.5             | 71.20            |
| PUMP INLET                              | 135.6            | 163.2<br>173.7                          | 89.4<br>89.4   | 69.5             | 71.77            |
| PUMP EXIT                               | 2523.0<br>16.0   | 400.0                                   | 0.151          | 204.7            | 0.12             |
| 02 TANK PRESS<br>OCV INLET              | 2497.8           | 173.8                                   | 89.3           | 69.5             | 71.73            |
| OCV EXIT                                | 1748.4           | 176.6                                   | 89.3           | 69.5             | 70.56            |
| CHAMBER INJ                             | 1713.6           | 176.8                                   | 89.3           | 69.5             | 70.51            |
| CHAMBER                                 | 1557.9           | • |                |                  |                  |
| OI WE IDEN                              |                  |   |                |                  |                  |
|   |                  |   |                |                  |                  |
|   |                  | VALVE DA                                |                | % BYPASS         |                  |
| VALVE                                   | DELTA P          | AREA                                    | FLOM           |                  |                  |
| TBV                                     | 2138.            | 0.03                                    | 0.75           | 5.00             |                  |
| FSOV                                    | 43.              | 3.73                                    | 14.88<br>89.29 |                  |                  |
| ocv                                     | 749.             | 0.58                                    | 07.67          |                  |                  |
|   |                  |   |                |                  |                  |
|   |                  | INJECTOR                                |                |                  |                  |
| INJECTOR                                | DELTA P          | AREA                                    | FLOH           | VELOCITY         |                  |
| FUEL                                    | 117.             | 2.58                                    | 14.88          | 1117.61          |                  |
| LOX.                                    | 173.             | 1.27                                    | 89.29          | 143.07           |                  |
|   |                  |   |                |                  |                  |

TABLE 28. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 50,000 LBF THRUST (COPPER TUBE CHAMBER) (CONTINUED)

|  | ERY PERFORMANCE DATA +                           |   |
|--|--|---|
| ********   | *************                                    |   |
|  | ***************************************          |   |
| * H2 BOOST TURBINE *   | * H2 BOOST PL                                    | P .   |
| *************  | ***************************************          | ****  |
| EFFICIENCY (T/T) 0.859<br>EFFICIENCY (T/S) 0.476                             | EFFICIENCY<br>HORSEPOHER                         | 0.765   |
| SPEED (RPH) 29231.   | SPEED (RPH)                                      | 96.<br>29251.<br>3045.                        |
| MEAN DIA (3H) 2.83<br>FFF ARFA (1H2) 5.39                                    | S SPEED  |   |
| SPEED (RPH) 29231. MEAN DIA (2H) 2.03 EFF AREA (1M2) 5.39 U/C (ACTUAL) 0.529 | HEAD (FT)<br>DIA. (IH)                           | 2702.<br>3.44                                 |
| MAX TIP SPEED 369.<br>STAGES 1<br>GAMMA 1.42                                 | TIP SPEED<br>VOL. PLON                           | 440.<br>1524.                                 |
|  | TIP SPEED<br>VOL. FLOH<br>MEAD COEF<br>FLOH COEF | 0.450   |
| PRESS RATIO (T/T) 1.81 PRESS RATIO (T/S) 1.82                                | PLON COEP  | 0.201   |
| HORSEPOHER 96. EXIT HACH HUMBER 0.11   |  |   |
| SPECIFIC SPEED 150.00  |  |   |
| SPECIFIC DIMETER 0.53  |  |   |
|  |  |   |
| · H2 TURBINE ·   | 1 12 PUMP  |   |
| ***********  | *******  | •   |
|  |  | STAGE THO STAGE THREE                         |
| EFFICIENCY (T/T) 8.876<br>EFFICIENCY (T/S) 8.825                             | EFFICIENCY 0.750<br>HORSEPONER 1749.             | 0.746 0.746<br>1752. 1753.<br>100000. 100000. |
| SPEED (BOWL) LANGAA  | SPEED (RPH) 100000.                              | 100000. 100000.                               |
| HORSEPOHER 5254.<br>HEAH DIA. (IH) 2,92                                      | \$ 97023) 1176.                                  | 1162. 1150.                                   |
| EFF AREA (INZ) 0.67  | HEAD (FT) 48371.                                 |   |
| HAX TIP SPEED 1413.  | TUP SPEED 1753.                                  | 4.02 4.02<br>1753. 1754.                      |
| 31MUL3 Z   | VOL. FLON 1472,<br>HEAD COEF 0.506               | 1435. 1404.<br>8.506 8.505                    |
| PRESS RATID (T/T) 1.83   | PLDH COEF 8.121                                  | 0.500   |
| PRESS RATIO (T/S) 1.89<br>EXIT MACH NUMBER 8.26                              | BEARING DN 3.80E+06                              |   |
| EXIT MACH NUMBER 8.26 SPECIFIC SPEED 63.23 SPECIFIC DIAMETER 1.18            | SWFT SIMETER 38.00                               |   |
|  |  |   |
| *************  | *********  | ••••  |
| # 02 BOOST TURBINE #   | * 02 B00ST PU                                    |   |
| ***************  | *41******  | ••••  |
| EFFICIENCY (1/1) 0.896<br>EFFICIENCY (1/3) 0.756                             | EFFICIENCY<br>HORSEPONER                         | 0.764<br>51.                                  |
| SPEED (RPH) 7817.  | PROFES (BRM)                                     | 7817.   |
| SPEED (RPH) 7817PEAN DIA (IN) 5.81 EFF AREA (IN2) 7.68 U/C (ACTUAL) 8.553    | S SPEED HEAD (PT) DIA. (IN)                      | 1026.<br>242.                                 |
| U/C (ACTUAL) 8.553   | DIA. (IN)  |   |
| STAGES 1   | VO. 8 M  | 3.05<br>132.<br>544.                          |
| GAMMA 1.42<br>PRESS RATIO (T/T) 1.81   | HEAD COEF<br>PLON COEF                           | 8.450<br>8.200                                |
| PRESS RATIO (T/S) 1.03   |  | *****   |
| HORSEPONER 51. EXIT MACH MARKER 0.04 SPECIFIC SPEED 95.36                    |  |   |
| SPECIFIC SPEED 95.36<br>SPECIFIC DIAMETER 0.90                               |  |   |
|  |  |   |
| *********  | 4000000000                                       |   |
| P D2 TURBINE P   | • 02 PUP •                                       |   |
|  | **********                                       |   |
| EFFICIENCY (T/T) 0.801<br>EFFICIENCY (T/S) 0.826                             | EFF1C1ENCY<br>HORSEPONER                         | 0.769<br>1013.                                |
| SPEED (RPH) 45615.   | SPEED (RPH)                                      | 45415.  |
|  | SS SPEED<br>S SPEED                              | 21168.<br>1874.                               |
| HEAN DIA (IN) 2.92<br>EFF AREA (IN2) 9.98<br>U/C (ACTUAL) 9.516              | HEAD (FT)<br>DIA. (IN)                           | 4788.<br>2.99                                 |
| MAX TIP SPEED 641.   | TIP SPEED  | 596.  |
| STAGES 2<br>GAMMA 1.42   | VOL. FLON<br>HEAD COEF                           | 559.<br>0.434                                 |
| PRESS RATIO (T/T) 1.11   | FLON COEF  | 0.157   |
| PRESS RATIO (T/S) 1.12<br>EXIT MACH MUMBER 8.89                              | DIAMETER RATIO<br>BEARING DN 1                   | 0.604<br>.37E+06                              |
| SPECIFIC SPEED 77.18 SPECIFIC DIAMETER 1.82                                  | SHAFT DIANETER                                   | 30.00   |
| S CONTRO DIFFERENT 1.86  |  |   |
| REGENERATUR DATA   |  |   |
|  | •  |   |
| COLD SIDE HOT SII<br>DELP 46.14 \$3.0  | <b>14</b>  |   |
| DELT 115.00 -102.0<br>AREA 1.03 3.1  |  |   |
| FLON 14.91 14.8  |  |   |
| EFFECTIVENESS 8.29<br>NTU 8.42   |  |   |
| CRATIO 8.89  |  |   |
| CHIN 49.96<br>REGEN Q 5785.66  |  |   |
|  |  |   |

TABLE 29. — FULL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER GROOVED CHAMBER)

|                                  |                           |                | E PARAMETER    |                  |                |
|----------------------------------|---------------------------|----------------|----------------|------------------|----------------|
| CHAM                             | BER PRESSU                | RE             |                | 1750.2           |                |
|                                  | ENGINE THR                |                |                | 7500.            |                |
|                                  | L ENGINE F                | LOW RATE       |                | 15.62            |                |
|                                  | VAC. ISP                  |                |                | 480.0            |                |
|                                  | IAT AREA<br>'LE AREA RA   | T10            |                | 2.10<br>1000.0   |                |
|                                  | LE EXIT DI                |                |                | 51.67            |                |
|                                  | NE HIXTURE                |                |                | 6.00             |                |
| ETA                              |                           |                |                | 0.993            |                |
|                                  | BER COOLAN                |                |                | 731.             |                |
|                                  | IBER COOLAN<br>LE/CHAMBER |                |                | 710.<br>5975.    |                |
|                                  |                           |                | CONDITIONS     |                  |                |
|                                  |                           |                |                | ***              |                |
| STATION                          | * FUEL<br>PRESS           |                | NDITIONS *     | ENTHALPY         | DENS1T         |
| B.P. INLET                       | 18.6                      | 37.4           | 2.23           | -107.5           | 4.37           |
| B.P. EXIT                        | 100.3                     | 38.5           | 2.23           | -103.0           | 4.39           |
| PUNP INLET                       | 100.3                     | 38.5           | 2.23           | -103.0           | 4.39<br>4.30   |
|                                  | 1804.9<br>3447.1          | 66.9<br>93.2   | 2.23<br>2.23   | 15.5<br>129.3    | 4.29           |
| 2ND STAGE EXIT<br>PUMP EXIT      | 5043.4                    | 117.8          | 2.23           | 239.0            | 4.32           |
| COOLANT INLET                    | 4993.0                    | 118.2          | 2.23           | 239.0            | 4.30           |
| COOLANT EXIT                     | 4262.4                    | 828.3          |                | 2913.2           | 0.86           |
| TBV INLET                        | 4219.8                    | 828.6          | 0.11           | 2913.2<br>2913.2 | 0.85<br>0.41   |
| TBV EXIT<br>02 TRB INLET         | 1959.7                    | 843.2<br>828.6 | 0.11<br>2.12   | 2913.2           | 0.85           |
| OZ TRB EXIT                      | 4219.8<br>3829.5          | 813.6          | 2.12           | 2850.5           | 0.80           |
|                                  | 3829.5                    | 813.4          | 2.12           | 2850.5           | 0.80           |
| H2 TRB EXIT                      | 2082.2                    | 723.0          | 2.12           | 2490.3           | 0.51           |
| H2 TRB DIFFUSER                  |                           | 723.1<br>723.1 | 2.12<br>2.12   | 2490.3<br>2490.3 | 0.50<br>0.50   |
| TILL BET TOR CILL                | 2033.1<br>2015.3          | 722.0          | 2.12           | 2485.6           | 0.49           |
| H2 BST TRB DIFF<br>O2 BST TRB IN | 1999.9                    | 722.1          | 2.12           | 2485.6           | 0.49           |
| 02 BST TRB IN                    | 1979.9                    | 722.2          | 2.12           | 2485.6           | 0.49           |
| O2 BST TRB OUT                   | 1971.0                    | 721.5          | 2.12           | 2483.0           | 0.48<br>0.48   |
| 02 BST TRB DIFF                  | 1969.5<br>18.6            | 721.6<br>739.1 | 2.12<br>0.0024 | 2483.0<br>2504.5 | 0.0047         |
| H2 TANK PRESS GOX HEAT EXCH IN   |                           | 737.1          | 2.23           | 2504.5           | 0.48           |
| GOX HEAT EXCH OUT                |                           | 727.4          | 2.23           | 2503.2           | 0.48           |
| FSOV INLET                       | 1949.9                    | 727.4          | 2.23           | 2503.2           | 0.48           |
| FSOV EXIT                        | 1901.1                    | 727.7          | 2.23           | 2503.2<br>2503.2 | 0.46           |
| CHAMBER INJ<br>CHAMBER           | 1862.3<br>1750.2          | 727.9          | 2.23           | 2303.2           | 0.43           |
|                                  | * OXYO                    |                | CONDITIONS     | s •              |                |
| STATION                          | PRESS                     |                |                | ENTHALPY         | DENS17         |
| B.P. INLET                       | 16.0                      | 162.7<br>163.2 | 13.4<br>13.4   | 61.1<br>61.5     | 71.17          |
| B.P. EXIT<br>PUMP INLET          | 135.6<br>135.6            | 163.2          | 13.4           | 61.5             | 71.20          |
| PUMP EXIT                        | 2834.5                    | 177.2          | 13.4           | 71.4             | 71.50          |
| 02 TANK PRESS                    | 16.0                      | 400.0          |                |                  | 0.12           |
|                                  | 2806.2                    | 177.3          | 13.4           | 71.4             | 71.46          |
| OCV EXIT                         | 1964.3                    | 180.6          | 13.4           | 71.4<br>71.4     | 70.15<br>70.09 |
| CHAMBER INJ<br>CHAMBER           | 1925.2<br>1750.2          | 180.7          | 13.4           | 71.4             | 70.07          |
|                                  |                           | VALVE DA       | ITA #          | •                |                |
| VALVE                            | DELTA P                   |                | FLON           | % BYPASS         |                |
| TBV                              | 2260.                     |                |                | 5.00             |                |
| FSOV                             | 49.                       | 0.68           | 2.23           |                  |                |
| ocv                              | 842.                      | 0.08           | 13.39          |                  |                |
|                                  | •                         | INJECTOR       | DATA #         |                  |                |
| INJECTOR                         | DELTA P                   | AREA           | FLOM           | VELOC1TY         |                |
| FUEL                             | 132.                      | 0.47           | 2.23           | 1504.14          |                |
| FOX                              | 194.                      | 0.18           | 13.39          | 152.10           |                |
|                                  |                           |                |                |                  |                |

TABLE 29. — FULL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  |                | ******                      |                   |                |             |
|--|----------------|-----------------------------|-------------------|----------------|-------------|
|  |                | INERY PERFORMANCE           |                   |                |             |
| *********  |                |                             |                   | ****           |             |
| # H2 BOOST TU  |                |                             | H2 BOOST P        |                |             |
| EFFICIENCY (T/T)   |                |                             | ********          |                |             |
| EFFICIENCY (T/S)   |                | HORSE                       | CIENCY<br>EPOHER  | 14.            |             |
|  | 75279.         | SPEEI                       | (RPM)             | 75279.         |             |
| MEAN DIA (IN)<br>EFF AREA (IN2)  |                |                             | EED               | 3050.          |             |
| U/C (ACTUAL)   |                | HEAD                        | (FT)<br>(IN)      | 2685.<br>1.33  |             |
| MAX TIP SPEED  |                |                             | SPEED             | 438.           |             |
| STAGES   | 1              |                             | FLON              | 228.           |             |
| GAMMA  | 1.44           |                             | COEF              | 0.450          |             |
| PRESS RATIO (T/T) PRESS RATIO (T/S)  | 1.02           | FLUM                        | WEF               | 0.201          |             |
| HORSEPOHER   | 14.            |                             |                   |                |             |
| EXIT HACH NUMBER   |                |                             |                   |                |             |
| SPECIFIC SPEED<br>SPECIFIC DIAMETER  | 146.08<br>0.51 |                             |                   |                |             |
| G CON TO DIMETER   | <b>v</b> .31   |                             |                   |                |             |
| ********   |                |                             | ******            | ••             |             |
| # H2 TURBINE   |                |                             | # H2 PUMP         |                |             |
|  | •              |                             | STAGE OME         |                | STAGE THREE |
|  |                |                             |                   |                | ********    |
| EFFICIENCY (T/T)   |                |                             | 0.615             | 0.621          | 0.626       |
| EFFICIENCY (T/S)   | 0.787          | HORSEPOHER<br>SPEED (RPM)   | 375.              | 360.           | 347.        |
| EFFICIENCY (T/S) SPEED (RPM) HORSEPOHER HEAN DIA. (IN) EFF AREA (IN2) U/C (ACTUAL) | 1082.          | SS SPFFD                    | 9340.             | 187500.        | 187500.     |
| MEAN DIA. (IN)   | 1.65           | S SPEED                     |                   | 797.           | 813.        |
| EFF AREA (IN2)   | 0.11           | HEAD (FT)                   |                   | 797.<br>55094. |             |
| U/C (ACTUAL) MAX TIP SPEED   |                | DIA. (IN)<br>TIP SPEED      | 2.29              |                |             |
| STAGES   | 3              | VOL. FLOW                   | 1874.<br>233.     |                | 232.        |
| GAMMA  | 1.44           | HEAD COEF                   |                   | 0.505          |             |
| PRESS RATIO (T/T) PRESS RATIO (T/S)  |                | FLOW COEF<br>DIAMETER RATIO | 0.095             |                |             |
| EXIT MACH NUMBER   |                | BEARING DN                  | 0.322<br>3.00F+06 |                |             |
| SPECIFIC SPEED   | 54.79          | SHAFT DIAMETER              |                   |                |             |
| SPECIFIC DIAMETER  | 1.42           |                             |                   |                |             |
| *******  | *****          | **                          |                   |                |             |
| # 02 BOOST TUR   |                |                             | D2 BOOST PU       |                |             |
| **********   |                |                             |                   |                |             |
| EFFICIENCY (T/T) EFFICIENCY (T/S)  |                | EFF1C                       | IENCY<br>POMER    | 0.764          |             |
| SPEED (RPM)  |                | SPEED                       | POHER<br>(RPM)    | 8.<br>20183.   |             |
| MEAN DIA (IN)  | 2.25           |                             | E <b>D</b>        | 3026.          |             |
| EFF AREA (IN2)   |                | HEAD                        | (FT)              | 242.           |             |
|  | 237.           | DIA.                        | (IN)<br>PEED      | 1.49<br>132.   |             |
| STAGES   | 1              | VOL. I                      |                   | 85.            |             |
| GAMMA PRESS RATIO (T/T)  | 1.44           | HEAD (                      |                   | 0.450          |             |
| PRESS RATIO (T/T) PRESS RATIO (T/S)  |                | FLOH (                      | COEF              | 0.200          |             |
| HORSEPOHER   | 8.             |                             |                   |                |             |
| EXIT MACH NUMBER   | 0.03           |                             |                   |                |             |
| SPECIFIC SPEED SPECIFIC DIAMETER   |                |                             |                   |                |             |
| SPECIFIC DIAMETER  | U.82           |                             |                   |                |             |
|  |                |                             | ********          |                |             |
| # 02 TURBINE #   |                |                             | 02 PUMP #         |                |             |
| EFFICIENCY (T/T)   | 0.00           |                             | ENCY              | 0.703          |             |
| EFFICIENCY (T/S)   |                |                             | DER.              | 188.           |             |
| SPEED (RPM)  | 127128.        | SPEED                       | (RPH)             |                |             |
| HORSEPOHER<br>MEAN DIA (IN)  | 188.           | SS SPE                      | ŒD<br>'n          | 22848.         |             |
| MEAN DIA (IN)<br>EFF AREA (IN2)  | 1.65<br>0.17   | 3 34 14                     |                   | 1843.<br>5434. |             |
| U/C (ACTUAL)   |                | DIA.                        | (FT)<br>(IN)      | 1.18           |             |
| MAX TIP SPEED  | 981.           | TIP SP                      | EED               | 653.           |             |
| STAGES   | 1              | VOL. F                      |                   | 84.            |             |
| GAMMA PRESS RATIO (T/T)  | 1.44           | HEAD O                      |                   | 0.410<br>0.155 |             |
| PRESS RATIO (T/S)  |                |                             | ER RATIO          | 0.155<br>0.681 |             |
| EXIT MACH NUMBER   | 0.09           | BEAR IN                     | IG DN :           | 1.53E+06       |             |
| SPECIFIC SPEED SPECIFIC DIAMETER   | 48.50          | SHAFT                       | DIAMETER          | 12.00          |             |
| SPECIFIC DIAMETER  | 1.52           |                             |                   |                |             |

# TABLE 30. — FULL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER GROOVED CHAMBER)

| ENGINE PERFORMANCE                        | E PARAMETERS |
|---|--------------|
| 在 沒 年 表 表 表 表 表 表 表 表 表 表 表 表 表 表 表 表 表 表 | ******       |

| CHAMBER PRESSURE       | 1556.2 |
|------------------------|--------|
| VAC ENGINE THRUST      | 15000. |
| TOTAL ENGINE FLOH RATE | 31.25  |
| DEL. VAC. ISP          | 480.0  |
| THROAT AREA            | 4.71   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EKIT DIAMETER   | 77.46  |
| FIGURE MIXTURE RATIO   | 6.00   |
| FTA C*                 | 0.993  |
| CHAMBER COOLANT DP     | 523.   |
| CHAMBER COOLANT DT     | 535.   |
| MOZZI E / CHAMRER O    | 9138.  |

# ENGINE STATION CONDITIONS

|                                  |         | SYSTEM CON | mitions +  |                  |         |
|----------------------------------|---------|------------|------------|------------------|---------|
|                                  | PRESS   | TEMP       | FLOH       | ENTHALPY         | DENSITY |
| STATION<br>B.P. INLET            | 18.6    | 37.4       | 4.47       | -107.5           | 4.37    |
| B.P. EXIT                        | 100.5   | 38.5       | 4.47       | -103.0           | 4.39    |
|                                  | 100.5   | 38.5       | 4.47       | -103.0           | 4.39    |
| PURP INLET                       | 1526.5  | 58.2       | 4.47       | -15.2            | 4.43    |
| IST STAGE EXIT                   | 2944.9  | 77.0       | 4.47       | 71.3             | 4.48    |
| 2ND STAGE EXIT                   | 4356.9  | 95.8       | 4.47       | 156.4            | 4.53    |
| PUMP EXIT                        | 4313.3  | 95.4       | 4.47       | 156.4            | 4.51    |
| *                                | 3789.8  | 630.7      | 4.47       | 2200.2           | 0.99    |
| COOLANT EXIT                     | 3751.9  | 630.9      | 0.22       | 2200.2           | 0.96    |
|                                  | 1742.3  | 642.6      | 0.22       | 2200.2           | 0.48    |
| TBV EXIT                         | 3751.9  | 630.9      | 4.25       | 2200.2           | 0.98    |
| 02 TRB INLET                     | 3374.2  | 618.6      | 4.25       | 2146.9           | 0.91    |
| OZ TRB EXIT                      | 3374.2  | 618.6      | 4.25       | 2146.9           | 0.91    |
| H2 TRB INLET                     | 1866.0  | 551.6      | 4.25       | 1873.8           | 0.59    |
| H2 TRB EXIT                      | 1834.4  | 551.7      | 4.25       | 1873.8           | 0.58    |
| HZ TRB DIFFUSER                  | 1816.1  | 551.7      | 4.25       | 1873.8           | 0.58    |
| H2 BST TRB IN                    | 1794.8  | 550.6      | 4.25       | 1869.1           | 0.57    |
| H2 BST TRB OUT                   | 1780.4  | 550.7      | 4.25       | 1869.1           | 9.57    |
| H2 BST TRB DIFF                  | 1762.6  | 550.7      | 4.25       | 1869.1           | 9.56    |
| 02 BST TRB IN                    | 1752.6  | 550.1      | 4.25       | 1866.5           | 8.56    |
| 02 BST TRB OUT                   | 1752.0  | 550.1      | 4.25       | 1866.5           | 0.56    |
| 02 BST TRB DIFF<br>H2 TANK PRESS | 18.6    | 562.4      | 0.0064     | 1883.2           | 6.0062  |
|                                  | 1742.3  | 554.7      | 6.46       | 1883.2           | 0.55    |
| GOX HEAT EXCH OUT                |         | 554.4      | 4.46       | 1881.8           | 0.55    |
| FSOV INLET                       | 1733.6  | 554.4      | 4.46       | 1881.6           | 0.55    |
|                                  | 1690.2  | 554.6      | 4.46       | 1881.6           | 0.54    |
| FSOV EXIT                        | 1655.8  | 554.7      | 4.46       | 1881.8           | 0.53    |
| CHAMBER INJ                      | 1556.2  | 334        |            |                  |         |
| CHAMBER                          | 1334.2  |            |            |                  |         |
|                                  | * DXY   |            | CONDITIONS |                  |         |
| STATION                          | PRESS   | TEMP       | FLOH       | ENTHALPY         | DENSITY |
| B.P. INLET                       | 16.0    | 162.7      | 26.8       | 61.1             | 71.17   |
| B.P. EXIT                        | 135.6   | 163.2      | 26.8       | 61.5             | 71.20   |
| PUMP INLET                       | 135.6   | 163.2      | 26.8       | 61.5             | 71.20   |
| PUMP EXIT                        | 2520.3  | 174.8      | 26.8       | 69.9             | 71.59   |
| 02 TANK PRESS                    | 16.0    | 400.0      | 0.045      | 204.7            | 0.12    |
| OCV INLET                        | 2495.1  | 174.9      | 26.8       | 69.9             | 71.55   |
| OCV EXIT                         | 1746.6  | 177.7      | 26.8       | 69.9             | 70.38   |
| CHAMBER INJ                      | 1711.8  | 177.8      | 26.8       | 69.9             | 70.33   |
| CHAMBER                          | 1556.2  |            |            |                  |         |
|                                  |         | # VALVE DA | TA =       |                  |         |
|                                  |         |            |            |                  |         |
| VALVE                            | DELTA P | AREA       | FLOR       | % BYPASS<br>5.00 |         |
| TBV                              | 2010.   | 0.01       | 0.22       | 5.UV             |         |
| FSOV                             | 43.     | 1.34       | 4.46       |                  |         |
| OCV                              | 749.    | 0.17       | 26.79      |                  |         |
| ■ INJECTOR DATA ■                |         |            |            |                  |         |

FLOH 4.46 26.79 VELOCITY

1321.67 143.17

DELTA P AREA 117. 0.92 173. 0.38

INJECTOR FUEL LOX

TABLE 30. — FULL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  | HERY PERFORMANCE DATA =                |                                   |
|--|--|-----------------------------------|
|  | MERT PERFURMANCE DATA B                |                                   |
| ******   | <b>在海里水水水水水水水水</b>                     |                                   |
| # H2 BOOST TURBINE #                             | # H2 BOOST P                           | UMP =                             |
| *************                                    | *****                                  |                                   |
| EFFICIENCY (T/T) 0.742<br>EFFICIENCY (T/S) 0.390 | EFFICIENCY                             | 0.766                             |
| SPEED (RPM) 53252.                               | HORSEPOWER<br>SPEED (RPM)              | 29.<br>53252.                     |
| MEAN DIA (IN) 1.16                               | S SPEED                                | 3049.                             |
| EFF AREA (INC) 1.76                              | HEAD (FT)                              | 2689.                             |
| U/C (ACTUAL) 0.553                               | DIA. (IN)                              | 1.89                              |
| MAX TIP SPEED 389.                               | TIP SPEED                              | 438.                              |
| STAGES 1   | VOL. FLON                              | 457.                              |
| GAMMA 1.37 PRESS RATIO (T/T) 1.01                | HEAD COEF<br>FLOW COEF                 | 0.450                             |
| PRESS RATIO (T/S) 1.02                           | ream coer                              | 0.201                             |
| HORSEPOHER 29.                                   |  |                                   |
| EXIT MACH NUMBER 0.11                            |  |                                   |
| SPECIFIC SPEED 146.55                            |  |                                   |
| SPECIFIC DIAMETER 0.52                           |  |                                   |
| 表 表 故 就 就 就 就 是 是 是 点 说 本                        | ****                                   |                                   |
| # H2 TURBINE #                                   | # H2 PUMP                              |                                   |
| *******  | *****                                  |                                   |
|  |  | STAGE THO STAGE THREE             |
| FET TOTAL CO.                                    |  | ******** ********                 |
| EFFICIENCY (T/T) 0.818 EFFICIENCY (T/S) 0.790    | EFFICIENCY 0.680                       |                                   |
| SPEED (RPM) 136363.                              | HORSEPOHER 556.<br>SPEED (RPM) 136363. | 547. 538.<br>136363. 136363.      |
| HORSEPOHER 1641.                                 | SS SPEED 9599.                         |                                   |
| MEAN DIA. (IN) 2.42                              | S SPEED 917.                           | 922. 927.                         |
| EFF AREA (IN2) 0.23                              | HEAD (FT) 46464.                       | 45825. 45101.                     |
| U/C (ACTUAL) 0.550                               | DIA. (IN) 2.85                         | 2.85 2.85                         |
| MAX TIP SPEED 1536.<br>STAGES 2                  | TIP SPEED 1694.                        | 1695. 1694.                       |
| GANHA 1.37                                       | VOL. FLOW 453.<br>HEAD COEF 0.521      | 448. 443.<br>0.513 0.5 <b>0</b> 5 |
| PRESS RATIO (T/T) 1.81                           | FLON COEF 0.105                        | 0.513 0.505                       |
| PRESS RATIO (T/S) 1.85                           | DIAMETER RATIO 0.363                   |                                   |
| EXIT MACH NUMBER 0.17                            | BEARING DN 3.00E+06                    |                                   |
| SPECIFIC SPEED 48.65                             | SHAFT DIAMETER 22.00                   |                                   |
| SPECIFIC DIAMETER 1.61                           |  |                                   |
| 网络 医乳蛋白蛋白 医乳毒素 医乳毒素 医乳毒素                         | *******                                |                                   |
| * 02 BOOST TURBINE #                             | # 02 BOOST PU                          | MP #                              |
|  | <b>国际保护业务</b>                          | F # M M                           |
| EFFICIENCY (T/T) 0.826                           | EFFICIENCY                             | 0.764                             |
| EFFICIENCY (T/S) 0.689  SPEED (RPM) 14271.       | HORSEPOHER                             | 15.                               |
| MEAN DIA (IN) 3.18                               | SPEED (RPM)<br>S SPEED                 | 14271.<br>3026.                   |
| EFF AREA (IN2) 2.59                              | HEAD (FT)                              | 242.                              |
| U/C (ACTUAL) 0.553                               | DIA. (IN)                              | 2.11                              |
| MAX TIP SPEED 234.                               | TIP SPEED                              | 152.                              |
| STAGES 1   | VOL. FLON                              | 169.                              |
| GAMMA 1.37 PRESS RATIO (T/T) 1.01                | HEAD COEF<br>FLON COEF                 | 0.450<br>0.200                    |
| PRESS RATIO (T/S) 1.01                           | read coer                              | 0.200                             |
| HORSEPOHER 15.                                   |  |                                   |
| EXIT MACH NUMBER 0.04                            |  |                                   |
| SPECIFIC SPEED 96.18                             |  |                                   |
| SPECIFIC DIAMETER 0.86                           |  |                                   |
|  |  |                                   |
| # 02 TURBINE #                                   | # 02 PUMP #                            |                                   |
| *******  | ********                               |                                   |
| EFFICIENCY (T/T) 0.821                           | <b>EFFICIENCY</b>                      | 0.730                             |
| EFFICIENCY (T/S) 0.767                           | HORSEPOHER                             | 321.                              |
| SPEED (RPH) 84487.<br>HORSEPOWER 321.            | SPEED (RPM)                            |                                   |
| MEAN DIA (IN) 2.42                               | SS SPEED<br>S SPEED                    | 21475.<br>1902.                   |
| EFF AREA (IN2) 0.33                              |  | 4795.                             |
| U/C (ACTUAL) 0.545                               | HEAD (FT)<br>DIA. (IN)                 | 1.64                              |
| MAX TIP SPEED 952.                               | TIP SPEED                              | 606.                              |
| STAGES 1   | VOL. FLOW                              | 168.                              |
| GAMMA 1.37                                       | HEAD COEF                              | 0.420                             |
| PRESS RATIO (T/T) 1.11 PRESS RATIO (T/S) 1.12    | FLOW COEF                              | 0.158                             |
| FYIT MACH MIMPED 0 10                            | DIAMETER RATIO BEARING DN 1            | 0.683<br>52F+06                   |
| SPECIFIC SPEED 48.53                             | SHAFT DIAMETER                         | 18.00                             |
| SPECIFIC DIAMETER 1.61                           |  |                                   |
|  |  |                                   |

TABLE 31. — FULL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER)

| **   | ENGINE PE                 | RFORMANCE      | PARAMETERS     |                  |                  |
|--|---------------------------|----------------|----------------|------------------|------------------|
| CHAM   | BER PRESSUR               | F              |                | 1491.7           |                  |
| -  | ENGINE THRU               |                | •              | 25000.           |                  |
|  | L ENGINE FL               | OW RATE        |                | 52.09            |                  |
|  | VAC. ISP                  |                |                | 480.0<br>8.19    |                  |
|  | AT AREA<br>LE AREA RAI    | 110            |                | 1000.0           |                  |
|  | LE EXIT DIA               |                |                | 102.12           |                  |
|  | NE MIXTURE                |                |                | 6.00             |                  |
| ETA  |                           |                |                | 0.993<br>473.    |                  |
|  | BER COOLAN                |                |                | 448.             |                  |
|  | BER COOLANT<br>LE/CHAMBER |                |                | 12774.           |                  |
|  | ENGINE                    | STATION C      | CONDITIONS     | ***              |                  |
|  |                           | PURTEM COM     | DITIONS #      |                  |                  |
| STATION  | PRESS                     | TEMP           | FLON           | ENTHALPY         | DENSITY          |
| B.P. INLET   | 18.6                      | 37.4           | 7.45           | -107.5           | 4.37             |
| B.P. EXIT  | 100.6                     | 38.5           | 7.45           | -103.0           | 4.39             |
| PUMP INLET   | 100.6                     | 38.5           | 7.45           | -103.0<br>-27.1  | 4.39<br>4.50     |
|  | 1433.1                    | 54.5<br>70.0   | 7.45<br>7.45   | 48.6             | 4.58             |
| 2ND STAGE EXIT PUMP EXIT                               | 2782.0<br>4147.2          | 85.1           | 7.45           | 123.9            | 4.67             |
| COOLANT INLET  | 4105.7                    | 85.5           | 7.45           | 123.9            | 4.65             |
| COOLANT EXIT   | 3632.5                    | 533.3          | 7.45           | 1837.8           | 1.11             |
| TBV INLET  | 3596.2                    | 533.5          | 0.37           | 1837.8<br>1837.8 | 1.10<br>0.54     |
| TBV EXIT   | 1670.3<br>3596.2          | 542.6<br>533.5 | 0.37<br>7.08   | 1837.8           | 1.10             |
| 02 TRB INLET<br>02 TRB EXIT                            | 3211.3                    | 521.9          | 7.08           | 1788.0           | 1.02             |
|  |                           | 521.9          | 7.08           | 1788.0           | 1.02             |
| H2 TRB INLET H2 TRB EXIT H2 TRB DIFFUSER H2 DST TRR IN | 1799.8                    | 463.1          | 7.08           | 1549.3<br>1549.3 | 0.68<br>0.66     |
| H2 TRB DIFFUSER  | 1760.7                    | 463.3          | 7.08<br>7.08   | 1549.3           | 0.66             |
| H2 BST TRB IN<br>H2 BST TRB OUT                        | 1743.1                    | 463.3<br>462.1 | 7.08           | 1544.5           | 0.65             |
| H2 BST TRB DIFF  | 1708.1                    | 462.2          | 7.08           | 1544.5           | 0.64             |
| MI AGT TOR IM  | 1691.0                    | 462.3          | 7.08           | 1544.5           | 0.64             |
| TUO BOT TOR OUT  | 1680.2                    | 461.6          | 7.08           | 1542.0           | 0.64<br>0.64     |
| 02 BST TRB DIFF  | 1678.7                    | 461.6          | 7.08<br>0.0127 | 1542.0<br>1556.8 | 0.0074           |
| H2 TANK PRESS<br>GOX HEAT EXCH IN                      |                           | 471.0<br>465.6 | 7.44           | 1556.8           | 0.63             |
| GOX HEAT EXCH OU                                       |                           | 465.3          | 7.44           | 1555.4           | 0.62             |
| FSOV INLET   | 1661.9                    | 465.3          | 7.44           | 1555.4           | 0.62             |
| FSOV EXIT  | 1620.4                    | 465.4          | 7.44           | 1555.4<br>1555.4 | 0.61             |
| CHAMBER INJ<br>CHAMBER                                 | 1587.3<br>1491.7          | 465.5          | 7.44           | 1555.4           |                  |
|  |                           |                | CONDITIONS     | \$ *             | B57 M 1 TW       |
| STATION  |                           |                | FLOR           | ENTHALPY<br>61.1 | DENSITY<br>71.17 |
| B.P. INLET   | 16.0                      | 162.7<br>163.2 | 44.7<br>44.7   | 61.5             | 71.20            |
| B.P. EXIT<br>PUMP INLET                                | 135.6<br>135.6            | 163.2          | 44.7           | 61.5             | 71.20            |
| PUMP EXIT  | 2415.8                    | 173.8          | 44.7           | 69.3             | 71.65            |
| 02 TANK PRESS  | 16.0                      | 400.0          | 0.076          | 204.7            | 0.12<br>71.61    |
| OCV INLET  | 2391.7                    | 173.9          | 44.6<br>44.6   | 69.3<br>69.3     | 70.50            |
| OCV EXIT   | 1674.2<br>1640.9          | 176.6<br>176.7 | 44.6           | 69.3             | 70.44            |
| CHAMBER INJ<br>CHAMBER                                 | 1491.7                    |                |                |                  |                  |
|  |                           | WALVE DA       | ATA =          |                  |                  |
| VALVE  | DELTA P                   |                | FLON           | * BYPASS         |                  |
| TBV  | 1926.<br>42.              | 0.02<br>2.14   | 0.37<br>7.44   | 5.00             |                  |
| FSOV<br>OCV  | 718.                      | 0.29           |                |                  |                  |
|  | •                         | INJECTOR       | DATA =         |                  |                  |
| INJECTOR   | DELTA P                   | AREA           | FLOH           | VELOC1TY         |                  |
| FUEL   | 112.                      | 1.47           |                | 1218.70          |                  |
| LOX  | 166.                      | 0.65           | 44.64          | 140.06           |                  |

TABLE 31. — FULL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

| •                                       | TURBONAC        | HINERY PERFORMANCE     | DATA #          |                          |                 |
|---|-----------------|------------------------|-----------------|--------------------------|-----------------|
|   |                 | **************         |                 |                          |                 |
| * H2 800ST TU                           |                 |                        | H2 BOOST P      |                          |                 |
| ********                                | *****           |                        | ********        |                          |                 |
| EFFICIENCY (T/T)                        |                 |                        | CIENCY          | 0.766                    |                 |
| EFFICIENCY (T/S) SPEED (RPM)            | 0.458<br>41277. |                        | POHER           | 48.                      |                 |
| MEAN DIA (IN)                           | 1 45            | S SPEEL                | O (RPM)         | 41277.<br>3 <b>948</b> . |                 |
| EFF AREA (IN2)                          | 2.72            |                        | (FT)            | 2694.                    |                 |
| U/C (ACTUAL)                            |                 | DIA.                   |                 | 2.43                     |                 |
| MAX TIP SPEED<br>STAGES                 | 374.<br>1       |                        | FLON            | 439.<br>742.             |                 |
|   |                 | HEAD                   |                 | 0.450                    |                 |
| PRESS RATIO (T/T)                       | 1.01            | FLON                   | COEF            | 0.281                    |                 |
| PRESS RATIO (T/S) HORSEPOWER            | 1.02            |                        |                 |                          |                 |
| EXIT NACH NUMBER                        | 48.<br>0.11     |                        |                 |                          |                 |
| SPECIFIC SPEED                          |                 |                        |                 |                          |                 |
| SPECIFIC DIAMETER                       | 0.53            |                        |                 |                          |                 |
| ********                                |                 |                        | ********        |                          |                 |
| # H2 TURBINE                            |                 |                        | # H2 PUMP       |                          |                 |
| ******                                  |                 |                        | ********        |                          |                 |
|   |                 |                        |                 |                          | STAGE THREE     |
| EFFICIENCY (T/T)                        | 0.869           | <b>EFFICIENCY</b>      | 0.727           | 0.726                    | 0.725           |
| EFFICIENCY (T/S)                        |                 | HORSEPOHER             | 880.            | 797.                     | 794.            |
| SPEED (RPM)                             | 125000.         | SPEED (RPM)            | 125000.         | 125000.                  | 125000.         |
| HORSEPOHER                              | 2391.           | SS SPEED               | 11347.          |                          |                 |
| MEAN DIA. (IN)<br>EFF AREA (IN2)        |                 | S SPEED<br>HEAD (FT)   | 1142.<br>42954. | 1136.<br>42738.          | 1131.<br>42491. |
| U/C (ACTUAL)                            | 0.550           | DIA. (IN)              | 3.04            |                          | 3.04            |
| MAX TIP SPEED                           | 1465.           | TIP SPEED              | 1658.           | 1658.                    | 1658.           |
| STAGES<br>GAMMA                         | 2<br>1.39       | VOL. FLON<br>HEAD COEF | 744.            | 730.                     | 717.            |
| PRESS RATIO (T/T)                       |                 | FLON COEF              | 0.503<br>8.119  | 0.500                    | 0.497           |
| PRESS RATIO (T/S)                       |                 | DIAMETER RATIO         |                 |                          |                 |
| EXIT MACH NUMBER                        |                 | BEARING DN             |                 |                          |                 |
| SPECIFIC SPEED SPECIFIC DIAMETER        |                 | SHAFT DIAMETER         | 24.00           |                          |                 |
| STEEL TO BIMETER                        | 1.55            |                        |                 |                          |                 |
| *******                                 |                 | HAI                    |                 |                          |                 |
| # 02 BOOST TUR                          |                 |                        | 02 BOOST PU     |                          |                 |
| EFFICIENCY (T/T)                        |                 |                        | **********      |                          |                 |
| EFFICIENCY (T/S)                        |                 | HORSEF                 | ENCY<br>POHER   | 26.                      |                 |
|   | 11054.          | SPEED                  | (RPH)           | 11054.                   |                 |
| MEAN DIA (IN)<br>EFF AREA (IN2)         |                 | S SPEE<br>HEAD         |                 | 3026.                    |                 |
| U/C (ACTUAL)                            |                 |                        | (IN)            | 242.<br>2.72             |                 |
| MAX TIP SPEED                           | 232.            | TIP SE                 |                 | 152.                     |                 |
| STAGES                                  |                 | VOL. F                 |                 | 282.                     |                 |
| PRESS RATIO (T/T)                       | 1.39<br>1.01    | HEAD C<br>FLON C       |                 | 0.450<br>0.200           |                 |
| PRESS RATIO (T/S)                       |                 | i com c                | ~~              | 0.200                    |                 |
| HORSEPOHER                              | 26.             |                        |                 |                          |                 |
| EXIT MACH NUMBER SPECIFIC SPEED         | 0.04<br>94.95   |                        |                 |                          |                 |
| SPECIFIC DIAMETER                       |                 |                        |                 |                          |                 |
|   |                 |                        |                 |                          |                 |
| *********                               |                 |                        | ********        |                          |                 |
| = 02 TURBINE =                          |                 |                        | 02 PUMP *       |                          |                 |
| EFFICIENCY (T/T)                        |                 |                        | ENCY            |                          |                 |
| EFFICIENCY (T/S)                        |                 | HORSEP                 | OHER            | 498.                     |                 |
| SPEED (RPM)                             | 63806.          | SPEED                  | (RPH)           |                          |                 |
| HORSEPOHER HEAN DIA (IN) EFF AREA (IN2) | 498.<br>2.46    | SS SPE<br>S SPEE       | ED<br>n         | 20937.<br>1918.          |                 |
| EFF AREA (IN2)                          | 0.51            |                        |                 | 4581.                    |                 |
| U/C (ACTUAL)                            | 0.435           | DIA.                   | (FT)<br>(IN)    | 2.11                     |                 |
| MAX TIP SPEED                           | 749.            | TIP SP                 | EED             | 588.                     |                 |
| STAGES<br>GAMMA                         | 1<br>1.39       | VOL. F<br>HEAD C       |                 | 280.<br>0.426            |                 |
| PRESS RATIO (T/T)                       |                 | FLOH C                 |                 | 0.426                    |                 |
| PRESS RATIO (T/S)                       | 1.13            |                        | ER RATIO        | 0.684                    |                 |
| EXIT MACH NUMBER SPECIFIC SPEED         | 0.11            |                        | G DN 1          |                          |                 |
| SPECIFIC SPEED SPECIFIC DIAMETER        |                 | SHAFT                  | DIAMETER        | 22.00                    |                 |
| - LOW TO DIMINETER                      | ,               |                        |                 |                          |                 |

TABLE 32. - FULL-EXPANDER ENGINE - 37,500 LBF THRUST (COPPER GROOVED CHAMBER)

|   |                  |           | E PARAMETER          |                                      |                        |
|---|------------------|-----------|----------------------|--------------------------------------|------------------------|
| ••  | *******          |           | *****                | *****                                |                        |
| CVA   | BER PRESSU       | DF        |                      | 1334.9                               |                        |
|   | ENGINE THR       |           |                      | 37500.                               |                        |
|   | L ENGINE F       |           |                      | 78.14                                |                        |
|   | VAC. ISP         |           |                      | 479.9                                |                        |
|   | AT AREA          |           |                      | 13.72<br>1000.0                      |                        |
| NOZZ<br>NOZZ  | LE AREA RA       | AMETER    |                      | 132.16                               |                        |
| ENGI  | NE MIXTURE       | RATIO     |                      | 6.00                                 |                        |
| ETA   | C*               |           |                      | 0.993                                |                        |
|   | BER COOLAN       |           |                      | 386.                                 |                        |
|   | BER COOLAN       |           |                      | 376.<br>16125.                       |                        |
| NOZZ  | LE/CHAMBER       | u         | •                    | 16125.                               |                        |
|   |                  |           | CONDITIONS           |                                      |                        |
|   | ********         | *****     | ********             |                                      |                        |
| STATION B.P. INLET B.P. EXIT PUMP INLET 1ST STAGE EXIT 2ND STAGE EXIT 2ND STAGE EXIT COOLANT INLET COOLANT INLET TBV INLET TBV INLET TBV EXIT 02 TRB INLET 02 TRB EXIT H2 TRB INLET 172 TRB INLET 172 TRB INLET 172 TRB DIFFUSER 172 TRB DIFFUSER 173 TRB DUT 174 BST TRB DUT 175 BST TRB DUT 175 BST TRB DUT 176 BST TRB DUT 177 BST TRB DUT 178 BST TRB DUT 179 BST TRB DUT 170 BST TRB DUT 170 BST TRB DUT 170 BST TRB DUT 171 BST TRB DUT 172 BST TRB DUT 173 BST TRB DUT 174 BST TRB DUT 175 BST TRB DUT 175 BST TRB DUT 175 BST TRB DUT 176 BST TRB DUT 177 BST TRB DUT 178 BST TRB DUT | u FIE            | SYSTEM CO | NDITIONS #           |                                      |                        |
| STATION   | PRESS            | TEMP      | FLOH                 | ENTHALPY                             | DENSIT                 |
| B.P. INLET  | 18.6             | 37.4      | 11.18                | -107.5                               | 4.37                   |
| B.P. EXIT   | 100.7            | 38.5      | 11.18                | -103.0                               | 4.39<br>4.39           |
| PUMP INLET  | 100.7            | 38.5      | 11.18                | -183.0                               | 4.52                   |
| 1ST STAGE EXIT  | 1267.6<br>2660.2 | 64.3      | 11.18                | 25.0                                 | 4.62                   |
| PIMP FXIT   | 3673.3           | 76.6      | 11.18                | 89.2                                 | 4.69                   |
| COOLANT INLET   | 3636.6           | 77.0      | 11.18                | 89.2                                 | 4.68                   |
| COOLANT EXIT  | 3250.7           | 452.5     | 11.18                | 1530.9                               | 1.17                   |
| TBV INLET   | 3218.2           | 452.7     | 0.56                 | 1530.7                               | 0.57                   |
| 1BV EXII  | 1494.5<br>3218.2 | 452.7     | 10.63                | 1530.9                               | 1.16                   |
| 02 TRB EXIT   | 2875.6           | 442.7     | 10.63                | 1487.4                               | 1.07                   |
| H2 TRB INLET  | 2875.6           | 442.7     | 10.63                | 1487.4                               | 1.07                   |
| H2 TRB EXIT   | 1623.9           | 394.1     | 10.63                | 1285.1                               | 0.72<br>0.70           |
| H2 TRB DIFFUSER   | 1581.6           | 394.2     | 10.63                | 1285.1                               | 0.70                   |
| H2 BST TRB OUT  | 1565.8           | 393.1     | 10.63                | 1260.3                               | 0.69                   |
| H2 BST TRB DIFF   | 1530.1           | 393.1     | 10.63                | 1280.3                               | 0.68                   |
| 02 BST TRB IN   | 1514.8           | 393.2     | 10.63                | 1280.3                               | 0.67                   |
| 02 BST TRB OUT  | 1503.5           | 392.5     | 10.63                | 1277.8                               | 0.67<br>0.67<br>0.0088 |
| 02 BST TRB DIFF   | 1502.0           | 392.5     | 10.63                | 1277.8                               | 0.0088                 |
| CON MENT EXCH IN  | 1494.5           | 395.8     | 11.16                | 1290.4                               | 0.66                   |
| GOX HEAT EXCH OU  | T 1487.0         | 395.5     | 11.16                | 1289.0<br>1289.0<br>1289.0<br>1289.0 | 0.66                   |
| FSOV INLET  | 1487.0           | 395.5     | 11.16                | 1289.0                               | 0.66                   |
| FSOV EXIT   | 1449.9           | 395.6     | 11.16                | 1289.0                               | 0.64                   |
| FSOV INLET<br>FSOV EXIT<br>CHAMBER INJ<br>CHAMBER   | 1420.3           | 395.6     | 11.16                | 1287.0                               | 0.43                   |
| CHARBER   | 1334.7           |           |                      |                                      |                        |
|   | # OXYG           | EN SYSTEM | CONDITION            | S =                                  |                        |
| STATION   | PRESS            | TEMP      | FLON                 | ENTHALPY                             | 21 17                  |
| B.P. INLET  | 16.0             | 162.7     | 67.1<br>67.1<br>67.1 | ENTHALPY<br>61.1<br>61.5             | 71.17                  |
| DIMP TALFT  | 135.6            | 163.2     | 6/.1                 | 61.5                                 | 71.20                  |
| PUMP EXIT   | 2162.0           | 172.3     | 67.1                 |                                      | 71.65                  |
| 02 TANK PRESS   | 16.0             | 400.0     | 0.114                | 204.7                                | 0.12                   |
| OCV INLET   | 2140.4           | 172.4     | 47.0                 | 68.3<br>68.3                         | 71.62<br>70.61         |
| OCV EXIT  | 1498.3           | 174.9     | 67.0<br>67.0         |                                      | 70.61                  |
| B.P. INLET B.P. EXIT PUMP INLET PUMP EXIT OZ TANK PRESS OCV INLET OV EXIT CHAMBER INJ CHAMBER   | 1334.9           | 173.0     | 07.4                 |                                      |                        |
|   |                  | VALVE DA  | ITA #                |                                      |                        |
|   |                  |           |                      |                                      |                        |
|   | DELTA P          | AREA      | FLOH                 | * BYPASS                             |                        |
| TBV   | 1724.            | 0.03      | 0.56<br>11.16        | 5.00                                 |                        |
| FSOV  | 37.<br>642.      | 0.47      | 66.97                |                                      |                        |
| OCV   | ****             | U.71      |                      |                                      |                        |

INJECTOR

FUEL

LOX

. INJECTOR DATA \*

FLON

11.16

66.97

AREA

2.28

1.03

DELTA P

100.

148.

VELOCITY

1117.82

132.38

TABLE 32. — FULL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

| _                                  |                |                        |                    |                 |                 |
|------------------------------------|----------------|------------------------|--------------------|-----------------|-----------------|
|                                    |                | INERY PERFORMANCE      |                    |                 |                 |
| •                                  | ********       | ***********            | ***                |                 |                 |
| * H2 BOOST TU                      |                |                        | ********           |                 |                 |
| * 112 80021 10                     |                |                        | H2 BOOST P         |                 |                 |
| EFFICIENCY (T/T)                   |                |                        | CIENCY             | 0.765           |                 |
| EFFICIENCY (T/S)                   |                | HORSE                  | EPOHER             | 72.             |                 |
|                                    | 33715.         |                        | D (RPM)            | 33715.          |                 |
| MEAN DIA (IN)<br>EFF AREA (IN2)    |                | S SP(<br>HEAD          |                    | 3047.           |                 |
| U/C (ACTUAL)                       |                |                        | (IN)               | 2697.<br>2.98   |                 |
| MAX TIP SPEED                      | 372.           |                        | SPEED              | 439.            |                 |
| STAGES                             | 1              |                        | FLON               | 1144.           |                 |
| GAMMA PRESS RATIO (T/T)            | 1.41           | HEAD                   |                    | 0.450           |                 |
| PRESS RATIO (T/S)                  |                | PLUN                   | COEF               | 0.201           |                 |
| HORSEPOHER                         | 72.            |                        |                    |                 |                 |
| EXIT MACH NUMBER                   |                |                        |                    |                 |                 |
| SPECIFIC SPEED SPECIFIC DIAMETER   | 150.00<br>0.54 |                        |                    |                 |                 |
| SPECIFIC DIAMETER                  | U.54           |                        |                    |                 |                 |
| ********                           |                |                        | *****              |                 |                 |
| # H2 TURBINE                       |                |                        | # H2 PUMP          | •               |                 |
| *******                            | •              |                        | ******             |                 |                 |
|                                    |                |                        |                    |                 | STAGE THREE     |
| EFFICIENCY (T/T)                   | 0.881          | <b>EFFICIENCY</b>      | 0.754              |                 | 0.752           |
| EFFICIENCY (T/S)                   |                | HORSEPOHER             | 1012.              | 1015.           | 1015.           |
| SPEED (RPM)                        |                | SPEED (RPM)            | 107143.            | 107143.         | 107143.         |
| HORSEPOHER HEAN DIA. (IN)          | 3042.<br>2.65  | SS SPEED<br>S SPEED    | 11905.             |                 |                 |
| EFF AREA (IN2)                     |                | HEAD (FT)              | 1325.<br>37518.    | 1310.<br>37553. | 1300.<br>37495. |
| U/C (ACTUAL)                       | 0.550          | DIA. (IN)              | 3.37               | 3.37            | 3.37            |
| MAX TIP SPEED                      | 1373.          | TIP SPEED              | 1575.              |                 | 1575.           |
| STAGES<br>GAMMA                    | 2<br>1.41      | VOL. FLOH<br>HEAD COEF | 1111.              | 1087.<br>0.487  | 1069.           |
| PRESS RATIO (T/T)                  |                | FLON COEF              | 0.487<br>0.130     | 0.487           | 0.486           |
| PRESS RATIO (T/S)                  |                | DIAMETER RATIO         |                    |                 |                 |
| EXIT MACH NUMBER                   |                | BEARING DN             |                    |                 |                 |
| SPECIFIC SPEED SPECIFIC DIAMETER   | 70.25<br>1.18  | SHAFT DIAMETER         | 28.00              |                 |                 |
|                                    | 1.10           |                        |                    |                 |                 |
| ********                           |                | **                     | ********           | ****            |                 |
| * 02 BOOST TUR                     |                |                        | 02 BOOST PU        |                 |                 |
| EFFICIENCY (T/T)                   |                | EFFIC:                 | ********           | 0.764           |                 |
| EFFICIENCY (T/S)                   |                |                        | POHER              | 39.             |                 |
| SPEED (RPM)                        | 9026.          | SPEED                  | (RPM)              | 9026.           |                 |
| MEAN DIA (IN)<br>EFF AREA (IN2)    | 5.03           | S SPEI                 |                    | 3026.           |                 |
| EFF AREA (IN2) U/C (ACTUAL)        | 5.58<br>0.553  | HEAD<br>DIA.           | (FT)<br>(IN)       | 242.<br>3.34    |                 |
| MAX TIP SPEED                      | 231.           | TIP SE                 |                    | 132.            |                 |
| STAGES                             | 1              | VOL. F                 |                    | 423.            |                 |
| GAMMA PRESS RATIO (T/T)            | 1.41           | HEAD (                 |                    | 0.450           |                 |
| PRESS RATIO (T/S)                  |                | FLOH (                 | OEF                | 0.200           |                 |
| HORSEPOHER                         | 39.            |                        |                    |                 |                 |
| EXIT MACH NUMBER                   | 0.04           |                        |                    |                 |                 |
| SPECIFIC SPEED                     | 93.77          |                        |                    |                 |                 |
| SPECIFIC DIAMETER                  | 0.91           |                        |                    |                 |                 |
| ********                           |                |                        | ******             |                 |                 |
| # 02 TURBINE #                     |                |                        | 02 PUMP =          |                 |                 |
| EFFICIENCY (T/T)                   | 0.000          |                        | *****              |                 |                 |
| EFFICIENCY (T/S)                   |                | EFFICI<br>HORSEP       |                    | 0.760           |                 |
| SPEED (RPM)                        |                |                        |                    | 653.<br>69369.  |                 |
| HORSEPOWER                         | 653.           | SS SPE                 | ED<br>D            | 19842.          |                 |
| MEAN DIA (IN)<br>EFF AREA (IN2)    | 2.65           |                        |                    | 1986.           |                 |
| U/C (ACTUAL)                       |                | HEAD                   | (FT)               | 4071.           |                 |
| MAX TIP SPEED                      | 647.           | DIA.<br>TIP SP         | (IN)<br>FFD        | 2.56<br>552.    |                 |
| STAGES                             | 2              | VOL. F                 |                    | 420.            |                 |
| GAMMA                              | 1.41           | HEAD C                 |                    | 0.431           |                 |
| PRESS RATIO (T/T)                  |                | FLOW C                 |                    | 0.162           |                 |
| PRESS RATIO (T/S) EXIT MACH NUMBER | 1.13<br>0.10   |                        | ER RATIO           | 0.686           |                 |
| SPECIFIC SPEED                     | 80.41          |                        | G DN 1<br>DIAMETER |                 |                 |
| SPECIFIC DIAMETER                  | 1.03           | 0.24 1                 |                    |                 |                 |
|                                    |                |                        |                    |                 |                 |

TABLE 33. — FULL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER)

| ENGINE   | PERFORMANCE PARAMETERS         |
|----------|--------------------------------|
| ******** | 1. 未本金额的企业的有效的现在分词 医电子电子 医电子电子 |

| CHAMBER PRESSURE       | 1342.3 |
|------------------------|--------|
| VAC ENGINE THRUST      | 50000. |
| TOTAL ENGINE FLON RATE | 104.18 |
| DEL. VAC. ISP          | 479.9  |
| THROAT AREA            | 18.19  |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 152.19 |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C#                 | 0.993  |
| CHAMBER COOLANT DP     | 361.   |
| CHAMBER COOLANT DT     | 365.   |
| NOZZLEZCHANBER Q       | 20902. |

| * FUEL SYSTEM CONDITIONS * |         |            |            |          |         |  |
|----------------------------|---------|------------|------------|----------|---------|--|
|                            | PRESS   | TEMP       | FLOH       | ENTHALPY | DENSITY |  |
| STATION                    | 18.6    | 37.4       | 14.91      | -107.5   | 4.37    |  |
| B.P. INLET                 | 100.7   | 38.5       | 14.91      | -103.0   | 4.39    |  |
| B.P. EXIT<br>PUMP INLET    | 100.7   | 38.5       | 14.91      | -103.0   | 4.39    |  |
| IST STAGE EXIT             | 1260.0  | 51.0       | 14.91      | -40.6    | 4.53    |  |
| 2ND STAGE EXIT             | 2449.2  | 63.2       | 14.91      | 22.0     | 4.64    |  |
| PUMP EXIT                  | 3666.8  | 75.1       | 14.91      | 84.8     | 4.74    |  |
| COOLANT INLET              | 3630.1  | 75.4       | 14.91      | 84.8     | 4.72    |  |
| COOLANT EXIT               | 3268.8  | 440.8      | 14.91      | 1486.4   | 1.20    |  |
| TBV INLET                  | 3236.1  | 440.9      | 0.75       | 1486.4   | 1.19    |  |
| TBV EXIT                   | 1502.6  | 647.3      | 0.75       | 1486.4   | 0.59    |  |
| D2 TRB INLET               | 3236.1  | 440.9      | 14.17      | 1486.4   | 1.19    |  |
| DE TRE EXIT                | 2884.1  | 431.0      | 14.17      | 1443.2   | 1.10    |  |
| H2 TRB INLET               | 2884.1  | 431.0      | 14.17      | 1443.2   | 1.10    |  |
| H2 TRB EXIT                | 1637.4  | 383.9      | 14.17      | 1245.3   | 0.74    |  |
| H2 TRB DIFFUSER            | 1590.4  | 384.0      | 14.17      | 1245.3   | 0.72    |  |
| H2 BST TRB IN              | 1574.5  | 384.0      | 14.17      | 1245.3   | 0.72    |  |
| H2 BST TRB OUT             | 1551.5  | 382.8      | 14.17      | 1240.6   | 0.71    |  |
| H2 BST TRB DIFF            | 1538.6  | 382.9      | 14.17      | 1240.6   | 0.70    |  |
| OZ BST TRB IN              | 1523.2  | 382.9      | 14.17      | 1240.6   | 0.69    |  |
| OZ BST TRB OUT             | 1511.7  | 382.3      | 14.17      | 1238.0   | 0.69    |  |
| OZ BST TRB DIFF            | 1510.1  | 382.3      | 14.17      | 1238.0   | 0.69    |  |
| H2 TANK PRESS              | 18.6    | 387.9      | 0.0309     | 1250.4   | 0.0090  |  |
| GOX HEAT EXCH IN           | 1502.6  | 385.5      | 14.88      | 1250.4   | 0.68    |  |
| GOX HEAT EXCH OUT          |         | 385.1      | 14.88      | 1249.0   | 0.68    |  |
| FSOV INLET                 | 1495.1  | 385.1      | 14.88      | 1249.0   | 0.68    |  |
| FSOV EXIT                  | 1457.7  | 385.2      | 14.88      | 1249.0   | 0.66    |  |
| CHAMBER INJ                | 1428.0  | 385.3      | 14.88      | 1249.0   | 0.65    |  |
| CHAMBER                    | 1342.3  |            |            |          |         |  |
|                            | # OXY   | EN SYSTEM  | CONDITIONS | s =      |         |  |
| STATION                    | PRESS   | TEMP       | FLOH       | ENTHALPY | DENSITY |  |
| B.P. INLET                 | 16.0    | 162.7      | 89.4       | 61.1     | 71.17   |  |
| B.P. EXIT                  | 135.6   | 163.2      | 89.4       | 61.5     | 71.20   |  |
| PUMP INLET                 | 135.6   | 163.2      | 89.4       | 61.5     | 71.20   |  |
| PUMP EXIT                  | 2173.9  | 172.2      | 89.4       | 68.3     | 71.69   |  |
| 02 TANK PRESS              | 16.0    | 400.0      | 0.151      | 204.7    | 0.12    |  |
| OCV INLET                  | 2152.2  | 172.3      | 89.3       | 68.3     | 71.65   |  |
| OCV EXIT                   | 1506.5  | 174.7      | 89.3       | 68.3     | 70.64   |  |
| CHAMBER INJ                | 1476.5  | 174.8      | 89.3       | 68.3     | 70.60   |  |
| CHAMBER                    | 1342.3  |            |            |          |         |  |
|                            |         | . VALVE DA | ATA #      |          |         |  |
| _                          | PC 74 7 | 4054       | FLOH       | % BYPASS |         |  |
| VALVE                      | DELTA P | AREA       | 0.75       | 5.00     |         |  |
| TBV                        | 1733.   | 0.03       | 14.88      | 5.00     |         |  |
| F\$0V                      | 37.     | 4.32       | 89.30      |          |         |  |
| ocv                        | 646.    | 0.62       | 87.30      |          |         |  |
| # INJECTOR DATA #          |         |            |            |          |         |  |
| INJECTOR                   | DELTA P | AREA       | FLON       | VELOCITY |         |  |
|                            | 101.    | 2.98       | 14.88      | 1104.05  |         |  |
| FUEL                       | 149.    | 1.37       | 89.30      | 132.72   |         |  |
| FOX                        | 4-7.    |            |            |          |         |  |

TABLE 33. — FULL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|   |              | ***************              |                     |                  |             |
|---|--------------|------------------------------|---------------------|------------------|-------------|
|   |              | INERY PERFORMANCE I          |                     |                  |             |
| *********   |              |                              | ******              |                  |             |
| # H2 BOOST TUR  |              |                              | H2 BOOST PI         |                  |             |
| *********   | ****         |                              | ********            |                  |             |
| EFFICIENCY (T/T)  | 0.861        | EFF 10                       | TENCY               | 0.765            |             |
| EFFICIENCY (T/S)  |              |                              | POMER               | 96.              |             |
| SPEED (RPM)   |              |                              | (RPM)               | 29193.           |             |
| MEAN DIA (IN)<br>EFF AREA (IN2)                         | 2.04         |                              | ED                  | 3047.            |             |
| U/C (ACTUAL)  | 5.08         | PLAU                         | (FT)<br>(IN)        | 2696.<br>3.44    |             |
| MAX TIP SPEED   | 368.         |                              | PEED                | 439.             |             |
| STAGES  | 1            |                              | FLON                | 1525.            |             |
| GAMMA   | 1.39         | HEAD                         |                     | 0.450            |             |
| PRESS RATIO (T/T) PRESS RATIO (T/S)                     | 1.01         | FLOH                         | COEF                | 0.201            |             |
|   |              |                              |                     |                  |             |
| HORSEPOHER  | 96.          |                              |                     |                  |             |
| EXIT MACH NUMBER SPECIFIC SPEED                         | 0.12         |                              |                     |                  |             |
| SPECIFIC DIAMETER                                       |              |                              |                     |                  |             |
| SPECIFIC DIAMETER                                       | 0.54         |                              |                     |                  |             |
| *********   |              |                              |                     |                  |             |
| # H2 TURBINE #  |              |                              | # H2 PUMP           | -                |             |
|   |              |                              | ********            |                  |             |
|   |              |                              |                     |                  | STAGE THREE |
|   |              |                              |                     |                  | *********   |
| EFFICIENCY (T/T)  |              | EFF ICIENCY                  | 0.766               | 0.765            | 0.764       |
| EFFICIENCY (T/S)  | U.837        | HORSEPOHER<br>SPEED (RPM)    | 1317.               | 1323.<br>100000. | 1326.       |
| SPEED (RPM) HORSEPOHER MEAN DIA. (IN) EFF AREA (IN2)    | 1964<br>1964 | SPEED (RPM)                  | 100000.<br>12833.   | 100000.          | 100000.     |
| MEAN DIA. (IN)  | 2.81         | S SPEED                      |                     | 1415.            | 1399.       |
| EFF AREA (IN2)  | 0.73         | HEAD (FT)                    | 37200.              | 1415.<br>37299.  | 37355.      |
| U/C (ACTUAL)  | 0.550        | DIA. (IN)                    | 3.63                | 3.63             | 3.63        |
| MAX TIP SPEED   | 1373.        | TIP SPEED                    | 1585.<br>1478.      | 1585.            | 1585.       |
| STAGES  | 2            | VOL. FLOW                    |                     | 1443.            | 1412.       |
| GAMMA   | 1.39         | HEAD COEF                    | 0.476               | 0.478            | 0.479       |
| PRESS RATIO (T/T)                                       |              | FLOW COEF                    | 0.136               |                  |             |
| PRESS RATIO (T/S) EXIT MACH NUMBER                      | 1.83<br>0.22 | DIAMETER RATIO<br>BEARING DN |                     |                  |             |
| SPECIFIC SPEED  | 75.88        | SHAFT DIAMETER               |                     |                  |             |
| SPECIFIC DIAMETER                                       |              | SHE I DIMETER                | 30.00               |                  |             |
|   |              |                              |                     |                  |             |
| *****   | ****         | **                           | *******             | ***              |             |
| # 02 BOOST TURE   |              |                              | 02 <b>800</b> ST PU |                  |             |
| ***********   |              |                              |                     |                  |             |
| EFFICIENCY (T/T) EFFICIENCY (T/S)                       |              |                              | IENCY<br>POMER      | 0.764<br>51.     |             |
| SPEED (RPM)   |              | PUKSEI                       | (RPM)               | 7814             |             |
| MEAN DIA (IN)   |              | S SPE                        |                     | 3026.            |             |
| EFF AREA (1N2)  | 7.24         | HEAD                         | (FT)                | 242.             |             |
| U/C (ACTUAL)  | 0.553        | DIA.                         | (IN)                | 3.85             |             |
| MAX TIP SPEED   | 230.         |                              | PEED                | 132.             |             |
| STAGES  | 1            | VOL. (                       |                     | 564.             |             |
| GAMMA   | 1.39         | HEAD (                       |                     | 0.450            |             |
| PRESS RATIO (T/T) PRESS RATIO (T/S)                     |              | FLON                         | COEF                | 0.200            |             |
| HUDSEDURED  | E 1          |                              |                     |                  |             |
| EXIT MACH NUMBER  | 0.04         |                              |                     |                  |             |
| EXIT MACH NUMBER<br>SPECIFIC SPEED<br>SPECIFIC DIAMETER | 93.13        |                              |                     |                  |             |
| SPECIFIC DIAMETER                                       | 0.92         |                              |                     |                  |             |
|   |              |                              |                     |                  |             |
| ********  |              | •                            | *******             |                  |             |
| * 02 TURBINE *  |              |                              | 02 PUMP #           |                  |             |
| ************  |              |                              |                     |                  |             |
| EFFICIENCY (T/T) EFFICIENCY (T/S)                       |              |                              | LENCY<br>POHER      | 0.769<br>866.    |             |
| SPEED (RPM)   |              |                              |                     | 42723.           |             |
| HORSEPOHER  | 866.         |                              |                     | 19827.           |             |
|   |              | S SPEE                       | ED<br>D             | 1976.            |             |
| MEAN DIA (IN)<br>EFF AREA (IN2)                         |              |                              | (FT)                | 4093.            |             |
| U/C (ACTUAL)  |              | DIA.                         | (IN)                | 2.95             |             |
| MAX TIP SPEED   | 601.         | TIP SE                       | -                   | 551.             |             |
| STAGES  | . 2          | VOL. F                       |                     | 560.             |             |
| GAMMA   | 1.39         | HEAD (                       |                     | 0.434            |             |
| PRESS RATIO (T/T)                                       | _            | FLON (                       |                     | 0.161            |             |
| PRESS RATIO (T/S) EXIT MACH NUMBER                      | 1.13         |                              | ER RATIO<br>4G DIN  | 0.686            |             |
| SPECIFIC SPEED  | 78.94        |                              | O UN<br>DIAMETER    |                  |             |
| SPECIFIC DIAMETER                                       |              | J. W. T.                     | SIME ILR            | 30.00            |             |
|   |              |                              |                     |                  |             |

# TABLE 34. — SPLIT-EXPANDER ENGINE — 7500 LBF THRUST (COPPER GROOVED CHAMBER)

| ENGINE | PERFORMANCE PARAMETERS |  |
|--------|------------------------|--|
| <br>   |                        |  |

| CHAMBER PRESSURE       | 1247.9 |
|------------------------|--------|
| VAC ENGINE THRUST      | 7500.  |
| TOTAL ENGINE FLOW RATE | 15.63  |
| DEL. VAC. ISP          | 479.9  |
| THROAT AREA            | 2.93   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 61.12  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA CH                 | 0.993  |
| CHAMBER COOLANT DP     | 1112.  |
| CHAMBER COOLANT DT     | 993.   |
|                        | 6.09.7 |

|                                | • FUEL           | SYSTEM CO        | NDITIONS #   |                  |              |  |  |
|--------------------------------|------------------|------------------|--------------|------------------|--------------|--|--|
| STATION                        | PRESS            | TEMP             | FLOH         | ENTHALPY         | DENSITY      |  |  |
| B.P. INLET                     | 18.6             | 37.4             | 2.23         | -107.5           | 4.37         |  |  |
| B.P. EXIT                      | 100.7            | 38.5             | 2.23         | -103.0           | 4.39         |  |  |
| PUMP INLET                     | 100.7            | 38.5             | 2.23         | -103.0           | 4.39         |  |  |
| IST STAGE EXIT                 | 1756.6           | 65.6             | 2.23         | 10.7             | 4.31         |  |  |
| JBV INLET                      | 1721.5           | 65.9             | 1.12         | 10.9             | 4.29         |  |  |
| JBV EXIT                       | 1463.2           | 67.8             | 1.12         | 10.9             | 4.09         |  |  |
| 2ND STAGE EXIT                 | 3105.7           | 92.3             | 1.12         | 119.1            | 4.18         |  |  |
| PUMP EXIT                      | 4354.6           | 116.4            | 1.12         | 218.8            | 4.14<br>4.12 |  |  |
| COOLANT INLET                  | 4311.0           | 116.7            | 1.12         | 218.8            | 0.50         |  |  |
| COOLANT EXIT                   | 3198.8           | 1110.0           | 1.12<br>0.06 | 3876.7<br>3876.7 | 0.50         |  |  |
| TBV INLET                      | 3166.8           | 1110.2           | 0.06         | 3876.7           | 0.24         |  |  |
| TBV EXIT                       | 1470.1           | 1122.3           | 1.06         | 3876.7           | 0.50         |  |  |
| 02 TRB INLET                   | 3166.8           | 1110.2<br>1087.4 | 1.06         | 3788.8           | 0.46         |  |  |
| 02 TRB EXIT                    | 2851.0           | 1087.4           | 1.06         | 3788.8           | 0.46         |  |  |
| H2 TRB INLET                   | 2851.0<br>1560.2 | 964.9            | 1.06         | 3329.9           | 0.29         |  |  |
| H2 TRB EXIT<br>H2 TRB DIFFUSER | 1542.9           | 965.0            | 1.06         | 3329.9           | 0.29         |  |  |
| H2 BST TRB IN                  | 1527.5           | 965.0            | 1.06         | 3329.9           | 0.29         |  |  |
| H2 BST TRB OUT                 | 1508.2           | 962.5            | 1.06         | 3320.4           | 0.28         |  |  |
| H2 BST TRB DIFF                | 1503.2           | 962.5            | 1.06         | 3320.4           | 0.28         |  |  |
| 02 BST TRB IN                  | 1488.1           | 962.6            | 1.06         | 3320.4           | 0.28         |  |  |
| OZ BST TRB OUT                 | 1478.2           | 961.2            | 1.06         | 3315.2           | 0.28         |  |  |
| 02 BST TRB DIFF                | 1477.5           | 961.2            | 1.06         | 3315.2           | 0.28         |  |  |
| H2 TANK PRESS                  | 18.6             | 979.5            | 0.0018       | 3343.3           | 0.0036       |  |  |
| GOX HEAT EXCH IN               | 1470.1           | 969.3            | 1.12         | 3343.3           | 0.27         |  |  |
| GOX HEAT EXCH DUT              |                  | 968.6            | 1.12         | 3340.5           | 0.27         |  |  |
| MIXER HOT IN                   | 1462.8           | 968.6            | 1.12         | 3340.5           | 0.27         |  |  |
| MIXER COLD IN                  | 1463.2           | 67.8             | 1.12         | 10.9             | 4.09         |  |  |
| MIXER OUT                      | 1389.6           | 498.7            | 2.23         | 1674.4           | 0.49         |  |  |
| FSOV INLET                     | 1389.6           | 498.7            | 2.23         | 1674.4           | 0.49         |  |  |
| FSOV EXIT                      | 1354.9           | 498.9            | 2.23         | 1674.4           | 0.48         |  |  |
| CHAMBER INJ                    | 1341.3           | 498.9            | 2.23         | 1674.4           | 0.48         |  |  |
| CHAMBER                        | 1247.9           |                  |              |                  |              |  |  |
|                                |                  |                  |              |                  |              |  |  |
|                                |                  |                  | CONDITIONS   |                  |              |  |  |
| STATION                        | PRESS            | TEMP             | FLOH         | ENTHALPY         | DENSITY      |  |  |
| B.P. INLET                     | 16.0             | 162.7            | 13.4         | 61.1             | 71.17        |  |  |
| B.P. EXIT                      | 135.6            | 163.2            | 13.4         | 61.5             | 71.20        |  |  |
| PUMP INLET                     | 135.6            | 163.2            | 13.4         | 61.5             | 71.20        |  |  |
| PUMP EXIT                      | 2020.9           | 173.0            | 13.4         | 68.4             | 71.41        |  |  |
| 02 TANK PRESS                  | 16.0             | 400.0            | 0.023        | 204.7            | 0.12         |  |  |
| OCV INLET                      | 2000.7           | 173.1            | 13.4         | 68.4             | 71.38        |  |  |
| OCV EXIT                       | 1400.5           | 175.4            | 13.4         | 68.4             | 70.43        |  |  |
| CHAMBER INJ                    | 1386.5           | 175.4            | 13.4         | 68.4             | 70.41        |  |  |
| CHAMBER                        | 1247.9           |                  |              |                  |              |  |  |
|                                |                  | * VALVE DA       | TA =         |                  |              |  |  |
|                                |                  | ,                |              |                  |              |  |  |
| VALVE                          | DELTA P          | AREA             | FLOH         | % BYPASS         |              |  |  |
| JBV                            | 258.             | 0.05             | 1.12         | 50.00            |              |  |  |
| TBV                            | 1697.            | 0.00             | 0.06         | 5.00             |              |  |  |
| FSOV                           | 35.              | 0.79             | 2.23         |                  |              |  |  |
| ocv                            | 600.             | 0.10             | 13.40        |                  |              |  |  |
| " INJECTOR DATA "              |                  |                  |              |                  |              |  |  |
|                                |                  |                  |              |                  |              |  |  |
| INJECTOR                       | DELTA P          | AREA             | FLOH         | VELOCITY         |              |  |  |
| FUEL                           | 93.              | 0.51             | 2.23         | 1238.05          |              |  |  |
| LOX                            | 139.             | 0.20             | 13.40        | 128.16           |              |  |  |
|                                |                  |                  |              |                  |              |  |  |

TABLE 34. — SPLIT-EXPANDER ENGINE — 7500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                                       | TARRARANANARANANANANANANANANANANANANANAN |  |  |
|---------------------------------------|--|--|--|
|                                       | CRT FERFORMANCE DATA                     |  |  |
| **************                        |  |  |  |
| * H2 BOOST TURBINE *                  |  | ****                                   |  |
|                                       |  | OOST PUMP #                            |  |
| EFFICIENCY (1/T) 0.789                |  | ********                               |  |
| EFFICIENCY (1/1) 0.789                | . EFFICIENC                              |  |  |
| SPEED (RPM) 75439.                    | HORSEPOHE                                |  |  |
|                                       | SPEED (                                  |  |  |
|                                       | S SPEED                                  | 3046.                                  |  |
|                                       |  | (FT) 2697.                             |  |
| U/C (ACTUAL) 0.553                    |  | (IN) 1.33                              |  |
| MAX TIP SPEED 484.                    | TIP SPEED                                |  |  |
| STAGES [                              | VOL. FLON                                | 228.                                   |  |
| GAMMA 1.42                            | HEAD COEF                                | 0.450                                  |  |
| PRESS RATIO (T/T) 1.01                | FLOH COEF                                | 0.201                                  |  |
| PRESS RATIO (T/S) 1.02                |  |  |  |
| HORSEPOHER 14.                        |  |  |  |
| EXIT MACH NUMBER 0.07                 |  |  |  |
| SPECIFIC SPEED 120.28                 |  |  |  |
| SPECIFIC DIAMETER 0.68                |  |  |  |
|                                       |  |  |  |
| *********                             |  | ****                                   |  |
| # H2 TURBINE #                        |  | PUMP =                                 |  |
| <b>医食用油胶等效医液体剂医食用</b>                 |  | HHHHOSE                                |  |
|                                       |  |  |  |
|                                       |  | E ONE STAGE THO STAGE THR              |  |
| EFFICIENCY (T/T) 0.776                |  |  |  |
| EFFICIENCY (T/S) 0.759                |  | .621 0.543 0.557                       |  |
| SPEED (RPM) 187500.                   | HORSEPOHER                               | 360. 171. 158.<br>500. 187500. 187500. |  |
|                                       | SPEED (RPM) 187                          | >UU. 187500. 187500.                   |  |
|                                       |  | 310.                                   |  |
| MEAN DIA. (IN) 2.28                   |  | 796. 656. 688.                         |  |
| EFF AREA (1N2) 0.09                   | HEAD (FT) 55                             | 008. 45817. 43238.                     |  |
| U/C (ACTUAL) 0.550                    |  | 2.26 2.13 2.13                         |  |
| MAX TIP SPEED 1933.                   |  | 847. 1743. 1743.                       |  |
| STAGES 2                              |  | 233. 120. 121.                         |  |
| GAPPA 1.42                            | HEAD COEF 0                              | .519 0.485 0.458                       |  |
| PRESS RATIO (T/T) 1.83                | FLOW COEF 0                              | .097                                   |  |
| PRESS RATIO (T/S) 1.85                | DIAMETER RATIO 0                         | . 327                                  |  |
| EXIT MACH NUMBER 0.13                 | BEARING DN 3.00                          | E+06                                   |  |
| SPECIFIC SPEED 31.97                  | SHAFT DIAMETER 1                         |  |  |
| SPECIFIC DIAMETER 2.34                |  |  |  |
|                                       |  |  |  |
| **************                        | ******                                   | ***                                    |  |
| # 02 BOOST TURBINE #                  |  | DST PUMP #                             |  |
| ***********                           |  | *****                                  |  |
| EFFICIENCY (T/T) 0.811                | EFF1C1ENCY                               |  |  |
| EFFICIENCY (T/S) 0.739                | HORSEPOHER                               |  |  |
| SPEED (RPM) 20181.                    | SPEED (RI                                |  |  |
| MEAN DIA (IN) 3.19                    |  |  |  |
|                                       | S SPEED                                  | 3026.                                  |  |
|                                       | HEAD (I                                  | FT) 242.                               |  |
| MAY TIP COEFF                         | DIA. (                                   |  |  |
| MAX TIP SPEED 307.<br>STAGES 1        | TIP SPEED                                |  |  |
| •                                     | VOL. FLON                                |  |  |
| GAMMA 1.42                            | HEAD COEF                                | 0.450                                  |  |
| PRESS RATIO (T/T) 1.01                | FLON COEF                                | 0.200                                  |  |
| PRESS RATIO (T/S) 1.01                |  |  |  |
| HORSEPOHER 8.                         |  |  |  |
| EXIT MACH NUMBER 0.03                 |  |  |  |
| SPECIFIC SPEED 61.32                  |  |  |  |
| SPECIFIC DIAMETER 1.30                |  |  |  |
|                                       |  |  |  |
| *********                             |  | 机装装等                                   |  |
| * 02 TURBINE *                        | • 02 F                                   | UNP #                                  |  |
| *******                               | *****                                    | ****                                   |  |
| EFFICIENCY (T/T) 0.778                | EFFICIENCY                               | 0.702                                  |  |
| EFFICIENCY (T/S) 0.750                | HORSEPOHER                               | 172                                    |  |
| SPEED (RPM) 109465.                   | SPEED IRE                                | M) 109465.                             |  |
| HORSEPOHER 132.                       | SS SPEED                                 | 19676.                                 |  |
| HORSEPONER 132.<br>MEAN DIA (IN) 2.28 | S SPEED                                  | 2077.                                  |  |
| EFF AREA (1N2) 0.13                   |  |  |  |
| U/C (ACTUAL) 0.519                    | HEAD (F<br>DIA, (I                       | T) 3801.                               |  |
| MAX TIP SPEED 1130.                   |  |  |  |
|                                       | TIP SPEED                                | 546.                                   |  |
| <del>-</del>                          | VOL. FLON                                | 84.                                    |  |
|                                       | HEAD COEF                                | 0.410                                  |  |
| PRESS RATIO (T/T) 1.11                | FLOH COEF                                | 0.165                                  |  |
| PRESS RATIO (T/S) 1.12                | DIAMETER RA                              |  |  |
| EXIT MACH NUMBER 0.07                 |  | 1.31E+06                               |  |
| SPECIFIC SPEED 30.59                  | SHAFT DIAME                              | TER 12.00                              |  |
| SPECIFIC DIAMETER 2.33                |  |  |  |

TABLE 35. — SPLIT-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER GROOVED CHAMBER)

|  | 01.00                    | , 22           |               | ,                |                       |
|--|--------------------------|----------------|---------------|------------------|-----------------------|
|  |                          |                |               |                  |                       |
|  |                          |                |               |                  |                       |
| **   | ENGINE PE                | ERFORMANCE     | PARAMETERS    | 5<br>****        |                       |
| CUAN   | BER PRESSU               | of.            |               | 1494.3           |                       |
|  | ENGINE THR               |                |               | 15000.           |                       |
| TOTA   | L ENGINE FI              |                |               | 31.25            |                       |
|  | VAC. ISP                 |                |               | 480.0<br>4.91    |                       |
|  | AT AREA<br>LE AREA RA    | 710            |               | 1000.0           |                       |
|  | LE EXIT DI               |                |               | 79.03            |                       |
| ENG1   | NE HIXTURE               | RATIO          |               | 6.00             |                       |
| ETA  | C=                       |                |               | 0.993            |                       |
|  | BER COOLAN               |                |               | 534.<br>1014.    |                       |
|  | BER COOLAN<br>LE/CHAMBER |                |               | 8357.            |                       |
|  | ENGINE                   | STATION C      | CONDITIONS    |                  |                       |
|  |                          |                |               | ***              |                       |
|  | FUEL                     | SYSTEM CON     | DITIONS #     | ENTHALPY         | DENS 1 TY             |
| STATION  |                          | TEMP           | FLOM<br>4.47  | -107.5           | 4.37                  |
| B.P. INLET   | 18.6<br>100.3            | 37.4<br>38.5   | 4.47          | -103.0           | 4.39                  |
| B.P. EXIT PUMP INLET   | 100.3                    | 38.5<br>38.5   | 4.47          | -103.0           | 4.39                  |
|  | 2103.5                   | 71.0           | 4.47          | 34.3             | 4.31                  |
| JBV INLET  | 2061.5                   | 71.4           | 2.23          | 34.3<br>34.3     | 4.28<br>4.07          |
| JBV EXIT   | 1752.3                   | 73.6<br>90.0   | 2.23<br>2.23  | 116.1            | 4.50                  |
| 2ND STAGE EXIT<br>PUMP EXIT                                  | 4408.2                   | 90.0<br>107.9  | 2.23          | 194.6            | 4.51                  |
| COOLANT INLET  | 4364.1                   | 108.2          | 2.23          | 194.6            | 4.29                  |
| COOLANT EXIT   | 3830.6                   | 1122.2         | 2.23          | 3935.2           | 0.59<br>0.58          |
| TBV INLET  |                          | 1122.5         | 0.11<br>0.11  | 3935.2<br>3935.2 | 0.28                  |
| TBV EXIT<br>OZ TRB INLET                                     | 1761.4                   | 1137.0         | 2.12          | 3935.2           | 0.58                  |
| O2 TRB EXIT  | 3792.3<br>3361.7         | 1096.3         | 2.12          | 3832.9           | 0.54                  |
| H2 TRB INLET   | 3361.7                   | 1096.3         | 2.12          | 3832.9           | 0.54                  |
| H2 TRB EXIT  | 3361.7<br>1864.0         | 975.8          | 2.12          | 3375.0<br>3375.0 | 0.34<br>0.34          |
| M2 TRB DIFFUSER M2 BST TRB IN M2 BST TRB OUT M2 BST TRB DIFF | 1846.0                   | 975.9<br>975.9 | 2.12<br>2.12  | 3375.0           | 0.34                  |
| H2 BST TRE IN  | 1827.6                   | 973.4          | 2.12          | 3365.5           | 0.33                  |
| H2 BST TRB DIFF  | 1800.6                   | 973.5          | 2.12          | 3365.5           | 0.33                  |
| n2 RST TRB IN  | 1782.6                   | 973.6          | 2.12          | 3365.5           | 0.33<br>0.33          |
| OZ BST TRB OUT   | 1771.0                   | 972.2          | 2.12<br>2.12  | 3360.4<br>3360.4 | 0.33                  |
| 02 BST TRB DIFF<br>H2 TANK PRESS                             | 17/0.3                   | 972.2<br>992.7 | 0.0036        | 3389.1           | 0.0035                |
| GOX HEAT EXCH IN   | 1761.4                   | 980.5          | 2.23          | 3389.1           | 0.32                  |
| GOX HEAT EXCH OU   |                          | 979.8          | 2.23          | 3386.4           | 0.32                  |
| MIXER HOT IN   | 1752.6                   | 979.8          | 2.23<br>2.23  | 3386.4<br>34.3   | 0.32<br>4. <b>0</b> 7 |
| MIXER COLD IN<br>MIXER OUT                                   | 1752.3<br>1665.0         | 73.6<br>507.2  | 4.46          | 1709.0           | 0.58                  |
| FSOV INLET   | 1665.0                   | 507.2          | 4.46          | 1709.0           | 0.58                  |
| FSOV EXIT  | 1623.3                   | 507.4          | 4.46          | 1709.0           | 0.56                  |
| CHAMBER INJ  | 1607.1                   | 507.4          | 4.46          | 1709.0           | 0.56                  |
| CHAMBER  |                          |                |               | _                |                       |
| STATION  | * 0XY                    | GEN SYSTEM     | CONDITION:    | ENTHALPY         | DENSITY               |
| B.P. INLET   | 16.0                     | 162.7          | 26.8          | 61.1             | 71.17                 |
| B.P. EXIT  | 135.6                    | 163.2          | 26.8          | 61.5             | 71.20                 |
| PUMP INLET   | 135.6                    | 163.2          | 26.8          | 61.5             | 71.20<br>71.58        |
| PUMP EXIT  | 2420.1                   | 174.3<br>400.0 | 26.8<br>0.045 | 69.5<br>204.7    | 0.12                  |
| 02 TANK PRESS<br>OCV INLET                                   | 16.0<br>2395.9           | 174.4          | 26.8          | 49.5             | 71.54                 |
| OCV EXIT   | 1677.1                   | 177.1          | 26.8          | 69.5             | 70.42                 |
| CHAMBER INJ  | 1660.3                   | 177.2          | 26.8          | 69.5             | 70.39                 |
| CHAMBER  | 1494.3                   |                |               |                  |                       |
|  |                          | • VALVE DA     | ATA =         |                  |                       |
| VALVE  | DELTA P                  | AREA           | FLOH          | % BYPASS         |                       |
| JBV  | 309.                     | 0.09           | 2.23          | 50.00            |                       |
| TBV  | 2031.                    | 0.01           | 0.11          | 5.00             |                       |
| FSOV   | 42.<br>719.              | 1.34           | 4.46<br>26.79 |                  |                       |
| OCV  | /17.                     | 3.10           | 23,           |                  |                       |

INJECTOR

FUEL

LOX

\* INJECTOR DATA \*

AREA

0.85

DELTA P

113. 166.

FLON

4.46

VELOCITY

140.26

TABLE 35. — SPLIT-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                                  | **********       | ****                      |                  |                |             |
|----------------------------------|------------------|---------------------------|------------------|----------------|-------------|
|                                  |                  | MERY PERFORMANCE          |                  |                |             |
|                                  |                  |                           |                  |                |             |
| * H2 BOOST TU                    |                  |                           |                  |                |             |
| * 72 8003) 10                    |                  |                           | H2 BOOST PI      |                |             |
| EFFICIENCY (T/T)                 |                  |                           | CIENCY           | 0.766          |             |
| EFFICIENCY (T/S)                 | 0.626            |                           | EPOWER           | 28.            |             |
| SPEED (RPM)                      | 53228.           | SPEE                      | (RPH)            | 53228.         |             |
| MEAN DIA (IN)                    |                  | S SPI                     | ED               | 3051.          |             |
| EFF AREA (IN2)                   |                  | HEAD                      |                  | 2684.          |             |
| U/C (ACTUAL) MAX TIP SPEED       |                  |                           | (IN)             | 1.88           |             |
| STAGES                           | 475.<br>1        |                           | SPEED<br>FLOW    | 438.<br>457.   |             |
| GAMMA                            | 1.44             | HEAD                      |                  | 0.450          |             |
| PRESS RATIO (T/T)                |                  | FLON                      |                  | 0.201          |             |
| PRESS RATIO (T/S)                | 1.02             |                           |                  |                |             |
| HORSEPOHER                       | 28.              |                           |                  |                |             |
| EXIT MACH NUMBER                 | 0.06             |                           |                  |                |             |
| SPECIFIC SPEED SPECIFIC DIAMETER | 116.15           |                           |                  |                |             |
| SPECIFIC DIAMETER                | 0.72             |                           |                  |                |             |
| *********                        | •                |                           | *****            |                |             |
| * HZ TURBINE                     | •                |                           | # H2 PUMP        |                |             |
| **********                       | •                |                           | *******          |                |             |
|                                  |                  |                           |                  |                | STAGE THREE |
| EEELOLENOU (***                  |                  |                           |                  |                | *********   |
| EFFICIENCY (T/T)                 |                  | EFFICIENCY                | 0.623            |                | 0.621       |
| EFFICIENCY (T/S) SPEED (RPM)     | 0.770<br>136363. | HORSEPOHER<br>SPEED (RPH) | 868.             | 259.           | 248.        |
| HORSEPOHER                       | 1375.            | SS SPEED (RPM)            | 136363.<br>9607. | 136363.        | 130363.     |
| MEAN DIA. (IN)                   |                  | S SPEED                   | 710.             | 748.           | 765.        |
| EFF AREA (IN2)                   | 0.15             | HEAD (FT)                 |                  | 39185.         | 37954.      |
| U/C (ACTUAL)                     | 0.537            | DIA. (IN)                 | 3.34             | 2.66           | 2.66        |
| MAX TIP SPEED                    | 1884.            | TIP SPEED                 | 1990.            | 1582.          | 1583.       |
| STAGES<br>GAMMA                  | 2                | VOL. FLON                 | 465.             | 233.           | 233.        |
| PRESS RATIO (T/T)                | 1.44             | HEAD COEF<br>FLOW COEF    | 0.541<br>0.090   | 0.503          | 0.488       |
| PRESS RATIO (T/S)                | 1.83             | DIAMETER RATIO            |                  |                |             |
| EXIT MACH NUMBER                 | 0.12             |                           | 3.00E+06         |                |             |
| SPECIFIC SPEED                   | 30.55            | SHAFT DIAMETER            |                  |                |             |
| SPECIFIC DIAMETER                | 2.41             |                           |                  |                |             |
| **********                       |                  |                           |                  |                |             |
| D2 BOOST TUR                     |                  |                           |                  |                |             |
| **********                       |                  |                           | D2 BOOST PU      |                |             |
| EFFICIENCY (T/T)                 |                  | EFFIC                     |                  | 0.764          |             |
| EFFICIENCY (T/S)                 | 0.760            | HORSE                     | POMER            | 15.            |             |
|                                  | 14271.           |                           | (RPM)            | 14271.         |             |
| MEAN DIA (IN)                    | 4.50             | S SPEI                    |                  | 3026.          |             |
| EFF AREA (IN2)                   |                  | HEAD                      |                  | 242.           |             |
| MAX TIP SPEED                    | 304.             | DIA.<br>TIP SI            | (IN)             | 2.11<br>132.   |             |
| STAGES                           | 1                | VOL.                      |                  | 169.           |             |
| GAMMA                            | 1.44             | HEAD (                    | OEF              | 0.450          |             |
| PRESS RATIO (T/T)                | 1.01             | FLOW (                    | COEF             | 0.200          |             |
| PRESS RATIO (T/S)                |                  |                           |                  |                |             |
| HORSEPOHER EXIT MACH NUMBER      | 15.<br>0.03      |                           |                  |                |             |
| SPECIFIC SPEED                   |                  |                           |                  |                |             |
| SPECIFIC DIAMETER                |                  |                           |                  |                |             |
|                                  |                  |                           |                  |                |             |
| **********                       |                  |                           | ********         |                |             |
| * 02 TURBINE *                   |                  |                           | 02 PUMP *        |                |             |
| EFFICIENCY (T/T)                 |                  |                           | ********         |                |             |
| EFFICIENCY (T/S)                 |                  | HORSEP                    | ENCY             | 0.730<br>307.  |             |
| SPEED (RPM)                      |                  |                           | (RPM)            | 82994.         |             |
| HORSEPOHER                       | 307.             | SS SPE                    |                  | 21095.         |             |
| MEAN DIA (IN)                    | 3.06             | S SPEE                    |                  | 1929.          |             |
| EFF AREA (IN2)                   |                  | HEAD                      | (FT)<br>(IN)     | 4595.          |             |
| U/C (ACTUAL)                     |                  | DIA.                      |                  | 1.64           |             |
|                                  | 1146.            | TIP SP                    |                  | 593.           |             |
| STAGES<br>GAMMA                  | 1<br>1.44        | VOL. F                    |                  | 168.           |             |
| PRESS RATIO (T/T)                |                  | HEAD C<br>FLOW C          |                  | 0.420<br>0.159 |             |
| PRESS RATIO (T/S)                | 1.13             |                           | ER RATIO         | 0.159          |             |
| EXIT MACH NUMBER                 | 0.06             |                           |                  | .49E+06        |             |
| SPECIFIC SPEED                   | 27.29            |                           | DIAMETER         | 18.00          |             |
| SPECIFIC DIAMETER                | 2.47             |                           |                  |                |             |

# TABLE 36. — SPLIT-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER)

|   |  |                         | E PARAMETER                    |                  |                |
|---|--|-------------------------|--------------------------------|------------------|----------------|
|   |  |                         |                                | 1554.4           |                |
|   | BER PRESSI<br>ENGINE THE                       |                         |                                | 1559.9<br>25000. |                |
|   | L ENGINE                                       |                         |                                | 52.08            |                |
|   | VAC. ISP                                       |                         |                                | 480.0            |                |
|   | AT AREA  |                         |                                | 7.83             |                |
|   | LE AREA RA                                     |                         |                                | 1030.0           |                |
|   | LE EXIT D                                      |                         |                                | 99.88<br>6.00    |                |
| ETA   |  | - 64110                 |                                | 0.993            |                |
|   | BER COOLA                                      | NT DP                   |                                | 539.             |                |
|   | BER COOLA                                      |                         |                                | 905.             |                |
| NO22  | LE/CHAMBE                                      | 3 0                     |                                | 12485.           |                |
|   |  |                         | CONDITIONS                     |                  |                |
|   | *****  |                         | *********                      | ***              |                |
|   |  |                         | NDITIONS *                     |                  |                |
| MOITATE   | PRESS  |                         | FLOH                           | ENTHALPY         | DENSITY        |
| B.P. INLET<br>B.P. EXIT                                       | 18.6<br>100.8                                  | 37.4<br>38.5            | 7 - 45<br>7 - 45               | -107.5<br>-103.0 | 4.37<br>4.39   |
| PUMP INLET  | 100.8  | 38.5                    | 7.45                           | -103.0           | 4.39           |
| 1ST STAGE EXIT  | 2195.6   | 67.8                    | 7.45                           | 27.4             | 4,44           |
|   | 2151.7   | 68.2                    | 3.72                           | 27.5             | 4.41           |
| JBV EXIT  | 1828.9   | 70.8                    | 3.72                           | 27.5             | 4.19<br>4.47   |
| 2ND STAGE EXIT<br>PUMP EXIT                                   | 3396.2   | 84.1                    | 3.72<br>3.72                   | 102.2<br>175.3   | 4.51           |
|   | 4537.7   | 99.8<br>100.2           | 3.72                           | 175.3            | 4.49           |
| COOLANT EXIT  | 3998.5   | 1004.9                  | 3.72                           | 3528.3           | 0.68           |
| TBV INLET   | 3958.5<br>1838.3<br>3958.5<br>3489.3<br>3489.3 | 1005.2                  | 0.19                           | 3528.3           | 0.67           |
| TBV EXIT  | 1838.3   | 1019.9                  | 0.19<br>3.54                   | 3528.3<br>3528.3 | 0.32<br>0.67   |
| O2 TRB INLET O2 TRB EXIT                                      | 3958.5<br>3489.3                               | 978.6                   | 3.54                           | 3423.9           | 0.62           |
| H2 TRB INLET  | 3489.3   | 978.6                   | 3.54                           | 3423.9           | 0.62           |
| H2 TRB EXIT   | 1949.5   | 866.0                   | 3.54                           | 2993.7           | 0.40           |
| H2 TRB DIFFUSER   | 1928.6   | 866.1                   | 3.54                           | 2993.7           | 0.40<br>0.40   |
| H2 BST TRB IN   | 1909.4   | 866.1                   | 3.54<br>3.54                   | 2993.7<br>2984.1 | 0.40           |
| H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT H2 BST TRB DIFF  | 1880.0   | 866.1<br>863.7<br>863.8 | 3.54<br>3.54                   | 2984-1           | 0.39           |
| O2 RST TOR IN   | 1861.2   | 863.7                   | 3.54                           | 2984.1           | 0.38           |
| 02 BST TRB OUT 02 BST TRB DIFF H2 TANK PRESS GOX HEAT EXCH IN | 1848.3   | 862.5                   | 3.54                           | 2979.0           | 0.38           |
| 02 BST TRB DIFF   | 1847.5   | 862.5                   | 3.54<br>0.0068<br>3.72<br>3.72 | 2979.0<br>3006.4 | 0.38<br>0.0040 |
| COY HEAT FYCH IN  | 1838.3   | 870.4                   | 3.72                           | 3006.4           | 0.38           |
| GOX HEAT EXCH OUT   | 1829.1   | 869.6                   | 3.72                           | 3003.7           | 0.38           |
| MIXER HOT IN  | 1829.1   | 869.6                   | 3 72                           | 3003.7           | 0.38           |
| MIXER COLD IN   | 1828.9   | 70.8                    | 3.72                           | 27.5<br>1514.2   | 4.19<br>0.67   |
| MIXER OUT<br>FSOV INLET                                       | 1737.6<br>1737.6                               | 454.0<br>454.0          | 7.44<br>7.44                   | 1514.2           | 0.67           |
| SECV EXIT   | 1694.2   | 454.1                   | 7.44                           | 1514.2           | 0.65           |
| CHAMBER INJ   | 1659.6   | 454.2                   | 7.44                           | 1514.2           | 0.64           |
| CHAMBER   | 1559.9   |                         |                                |                  |                |
|   | = OXY  | EN SYSTEM               | CONDITIONS                     | FORTUM DV        | DENSITY        |
| STATION<br>B.P. INLET   | PRESS<br>16.0                                  | 162.7                   | 44.7                           | ENTHALPY<br>61.1 | 71.17          |
| 0 0 EVIT  | 175 (  | 147 2                   | 44.7                           | 61.5             | 71.20          |
| PUMP INLET PUMP EXIT  | 135.6  | 163.2                   | 44.7                           | 61.5             | 71.20          |
| PUMP EXIT   | 2526.3   | 174.3                   | 44.7<br>0.076                  | 69.7             | 71.68          |
| UZ TAME PRESS   | 10.0   | 400.0                   |                                | 204.7<br>69.7    | 0.12<br>71.64  |
| OCV INLET<br>OCV EXIT   | 2501.1<br>1750.8                               | 174.4<br>177.2          | 44.6<br>44.6                   | 69.7             | 70.47          |
| CHAMBER INJ   | 1715.9   | 177.4                   | 44.6                           | 69.7             | 70.41          |
| CHAMBER   | 1559.9   |                         |                                |                  |                |
|   | 1  | VALVE DA                | TA =                           |                  |                |
| VALVE   | DELTA P  | AREA                    | FLON                           | % BYPASS         |                |
| JBV   | 323.   |                         | 3.72                           | 50.00            |                |
| TBV   | 2120.  | 0.01                    | 0.19                           | 5.00             |                |
| FSOV<br>OCV   | 43.<br>750.                                    | 2.02<br>0.29            | 7.44<br>44.64                  |                  |                |
| <b>~</b> ₹  |  |                         |                                |                  |                |
|   | •  | INJECTOR                | DATA =                         |                  |                |
| INJECTOR  | DELTA P  | AREA                    | FLOM                           | VELOCITY.        |                |
| FUEL  | 117.   | 1.39                    | 7.44                           | 1206.29          |                |
| FOX   | 173.   | 0.64                    | 44.64                          | 143.26           |                |

TABLE 36. — SPLIT-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  |                  | Y PERFORMANCE D              |                  |                          |                |
|--|------------------|------------------------------|------------------|--------------------------|----------------|
| ***                                    | *********        | **********                   |                  |                          |                |
| ###################################### |                  |                              | ********         |                          |                |
| " LE BOOZI LOKBY                       | _                |                              | H2 BOOST PL      |                          |                |
| EFFICIENCY (T/T)                       | 0.873            |                              | IENCY            | 0.765                    |                |
|  | 0.685            |                              | POHER            | 48.                      |                |
| SPEED (RPM) 4<br>MEAN DIA (IN)         |                  |                              | (RPM)            | 41343.                   |                |
|  | 2.12<br>1.68     | S SPE<br>HEAD                |                  | 3045.<br>27 <b>00</b> .  |                |
| U/C (ACTUAL)                           |                  | DIA.                         |                  | 2.43                     |                |
|  | 469.             |                              | PEED             | 439.                     |                |
| STAGES<br>GAMMA                        | 1                | VOL.<br>HEAD                 | FLON             | 761.                     |                |
| PRESS RATIO (T/T)                      |                  |                              | COEF             | 0.450<br>0.2 <b>9</b> 1  |                |
|  | 1.02             |                              |                  |                          |                |
| HORSEPONER                             | 48.              |                              |                  |                          |                |
|  | 0.07<br>14.44    |                              |                  |                          |                |
|  | 0.75             |                              |                  |                          |                |
|  |                  |                              |                  |                          |                |
| **********                             |                  |                              |                  |                          |                |
| # H2 TURBINE #                         |                  |                              | * H2 PUMP        |                          |                |
|  |                  |                              |                  |                          | STAGE THREE    |
|  |                  |                              | ******           | *******                  | ********       |
|  |                  | EFFICIENCY                   | 8.672            | 0.668                    |                |
| SPEED (RPH) 125                        |                  | HORSEPOHER<br>SPEED (RPM)    | 1375.<br>125000. | 394.<br>125 <b>00</b> 0. | 385.<br>125000 |
|  |                  | SS SPEED                     | 11322.           | 123000.                  | 113000.        |
|  | 3.13             | S SPEED                      | 813.             | 874.                     | 883.           |
|  |                  | EAD (FT)                     | 68187.           | 38830.                   | 38091.         |
| U/C (ACTUAL) 0 MAX TIP SPEED 1         |                  | DIA. (IN)<br>TIP SPEED       | 3.70<br>2019.    | 2.87<br>1566.            | 2.87<br>1565.  |
|  |                  | /OL. FLOH                    | 754.             | 374.                     | 371.           |
|  |                  | EAD COEF                     | 8.538            | 0.510                    | 0.500          |
|  |                  | FLOW COEF                    | 0.098            |                          |                |
| EXIT MACH NUMBER                       | 0.13             | DIAMETER RATIO<br>BEARING DN |                  |                          |                |
| SPECIFIC SPEED 3                       | 6.39             | SHAFT DIAMETER               |                  |                          |                |
| SPECIFIC DIAMETER                      | 2.04             |                              |                  |                          |                |
| **********                             |                  | ***                          |                  |                          |                |
| # 02 BOOST TURBIN                      | E =              |                              | 02 BOOST PU      |                          |                |
| ***********                            |                  |                              | ********         |                          |                |
| EFFICIENCY (T/T) 0 EFFICIENCY (T/S) 0  |                  | EFFIC:<br>HORSEF             | TENCY            | 0.764<br>26.             |                |
| SPEED (RPM) 11                         |                  |                              | (RPH)            | 11055.                   |                |
|  | 5.82             | S SPEE                       |                  | 3026.                    |                |
|  | 2.32             | HEAD                         | (FT)<br>(IN)     | 242.                     |                |
|  | .553<br>302.     | TIP SF                       |                  | 2.72<br>132.             |                |
| STAGES                                 | 1                | VOL. F                       |                  | 282.                     |                |
|  | 1.44             | HEAD (                       |                  | 0.450                    |                |
|  | 1.01<br>1.01     | FLOH C                       | COEF             | 0.200                    |                |
|  | 26.              |                              |                  |                          |                |
|  | 0.03             |                              |                  |                          |                |
|  | 5.25             |                              |                  |                          |                |
| SPECIFIC DIAMETER                      | 1.48             |                              |                  |                          |                |
| **********                             |                  |                              | ******           |                          |                |
| # 02 TURBINE #                         |                  |                              | 02 PUMP #        |                          |                |
| EFFICIENCY (T/T) 0                     | 0£7              |                              | ENCY             | 0.747                    |                |
| EFFICIENCY (T/S) 0                     |                  |                              | POMER            | 0.747<br>522.            |                |
| SPEED (RPM) 650                        |                  |                              |                  | 65070.                   |                |
|  | 522.             | SS SPE                       |                  | 21352.                   |                |
|  | 3.13<br>0.30     | S SPEE                       | D                | 1686.<br>4861.           |                |
| U/C (ACTUAL) 0.                        |                  | DIA.                         | (FT)<br>(IN)     | 2.12                     |                |
| MAX TIP SPEED                          | 939.             | TIP SP                       | EED              | 602.                     |                |
|  | 2                | VOL. F                       |                  | 288.                     |                |
|  | l.44<br>l.13     | HEAD C                       |                  | 0.426                    |                |
|  | l . 13<br>l . 14 |                              | ER RATIO         | 0.157<br>0.684           |                |
| EXIT MACH NUMBER (                     | 0.07             |                              | IG DN 1          |                          |                |
| SPECIFIC SPEED 43                      |                  | SHAFT                        | DIAMETER         | 22.00                    |                |
| SPECIFIC DIAMETER 1                    | 1.80             |                              |                  |                          |                |

#### TABLE 37. — SPLIT-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER GROOVED CHAMBER)

| **                                | ENGINE PI                 |                | PARAMETER      |                  |                      |
|-----------------------------------|---------------------------|----------------|----------------|------------------|----------------------|
| •                                 |                           | · ·            |                | 1465.3           |                      |
|                                   | IBER PRESSU<br>ENGINE THR |                |                | 37500.           |                      |
| TOTA                              | L ENGINE FI               |                |                | 78.13            |                      |
|                                   | VAC. ISP                  |                |                | 480.0<br>12.51   |                      |
|                                   | AT AREA<br>LE AREA RA     | TIO            |                | 1000.0           |                      |
| NOZZ                              | LE EXIT DI                | AMETER         |                | 126.19           |                      |
|                                   | NE MIXTURE                | RATIO          |                | 6.00<br>0.993    |                      |
| ETA<br>CHAR                       | C#<br>IBER COOLAN         | TDP            |                | 484.             |                      |
|                                   | BER COOLAN                |                |                | 784.             |                      |
| NOZZ                              | LE/CHAMBER                | Q              |                | 16332.           |                      |
|                                   |                           |                | CONDITIONS     | ***              |                      |
|                                   | # FUEL                    | SYSTEM CO      | NDITIONS .     |                  |                      |
| STATION                           | PRESS                     |                |                | ENTHALPY         | DENS I TY<br>4 . 3 7 |
| B.P. IMLET<br>B.P. EXIT           | 18.6<br>100.8             | 37.4<br>38.5   | 11.17<br>11.17 | -107.5<br>-103.0 | 4.39                 |
| PUMP INLET                        | 100.8                     | 38.5           | 11.17          | -103.0           | 4.39                 |
| IST STAGE EXIT                    |                           | 63.4           | 11.17          | 12.4             | 4.50<br>4.47         |
| JBV INLET<br>JBV EXIT             | 2021.5                    | 63.8<br>66.5   | 5.59<br>5.59   | 12.4<br>12.4     | 4.27                 |
| 2ND STAGE EXIT                    | 1718.2<br>3172.9          | 76.9           | 5.59           | 77.0             | 4.56                 |
| PUMP EXIT                         | 4283.4                    | 90.1           | 5.59           | 140.8            | 4.61                 |
| COOLANT INLET                     | 4240.6                    | 90.5<br>874.3  | 5.59<br>5.59   | 140.8<br>3064.3  | 4.59<br>0.73         |
| COOLANT EXIT TBV INLET            | 3756.2<br>3718.6          | 874.5          | 0.28           | 3064.3           | 0.72                 |
| TBV EXIT                          | 1726.8                    | 887.6          | 0.28           | 3064.3           | 0.35                 |
| 02 TRB INLET                      | 3718.6                    | 874.5<br>850.4 | 5.31<br>5.31   | 3064.3<br>2968.4 | 0.72                 |
| 02 TRB EXIT                       | 3257.5<br>3257.5          | 850.4          | 5.31           | 2968.4           | 0.66                 |
| H2 TRB INLET<br>H2 TRB EXIT       | 1841.2                    | 752.7          | 5.31           | 2590.3           | 0.43                 |
| HE TRB DIFFUSER                   | 1817.0                    | 752.9          | 5.31           | 2590.3<br>2590.3 | 0.43                 |
| HE BST TRB IN<br>HE BST TRB OUT   | 1798.8<br>1772.8          | 752.9<br>750.4 | 5.31<br>5.31   | 2580.7           | 0.42                 |
| HE BST TRB DIFF                   |                           | 750.5          | 5.31           | 2580.7           | 0.42                 |
| DZ BST TRB IN                     | 1750.1                    | 750.6          | 5.31           | 2580.7<br>2575.6 | 0.42                 |
| 02 BST TRB OUT<br>02 BST TRB DIFF | 1736.2<br>1735.4          | 749.2<br>749.2 | 5.31<br>5.31   | 2575.6           | 0.41                 |
| HZ TANK PRESS                     |                           | 766.5          | 0.0117         | 2600.0           | 0.0046               |
| GOX HEAT EXCH IN                  | 1726.8                    | 756.2          | 5.57           | 2600.0           | 0.41                 |
| GOX HEAT EXCH OU<br>MIXER HOT IN  |                           | 755.5<br>755.5 | 5.57<br>5.57   | 2597.2<br>2597.2 | 0.41                 |
| HIXER COLD IN                     | 1718.2                    | 66.5           | 5.59           | 12.4             | 4.27                 |
| MIXER OUT                         | 1632.2                    | 398.8          | 11.16          | 1303.5           | 0.71                 |
| FSOV INLET<br>FSOV EXIT           | 1632.2<br>1591.4          | 398.8<br>398.9 | 11.16<br>11.16 | 1303.5<br>1303.5 | 0.71                 |
| CHAMBER INJ                       | 1559.0                    | 399.0          |                |                  | 0.68                 |
| CHAMBER                           | 1465.3                    |                |                |                  |                      |
|                                   |                           | EN SYSTEM      | CONDITION      | 5 *              | DENS1T               |
| STATION<br>B.P. INLET             | PRESS<br>14.0             | 1/2 7          | 471            | ENTHALPY<br>61.1 | 71.17                |
| B.P. EXIT                         | 16.0<br>135.6             | 163.2          | 67.1           | 61.1<br>61.5     | 71.20                |
| PUMP INLET                        | 135.4                     | 163.2          | 67.1           | 61.5             | 71.20                |
| PUMP EXIT                         | 2373.1                    | 173.2<br>400.0 | 67.1<br>0.113  | 69.0<br>204.7    | 71.70<br>0.12        |
| 02 TANK PRESS<br>0CV INLET        | 16.0<br>2349.3            | 173.3          | 67.0           | 69.0             | 71.66                |
| DCV EXIT                          | 1644.5                    | 176.0          | 67.0           | 69.0             | 70.56                |
| CHAMBER INJ                       | 1611.8                    | 176.1          | 67.0           | 69.0             | 70.51                |
| CHAMBER                           | 1465.3                    |                |                |                  |                      |
|                                   |                           | WALVE DA       | ATA =          |                  |                      |
| VALVE                             | DELTA P                   | AREA           | FLON           | % BYPASS         |                      |
| J5V                               | 303.                      | 0.23           | 5.59           | 50.00<br>5.00    |                      |
| TBV<br>FSOV                       | 1992.<br>41.              | 0.02<br>3.02   | 0.29<br>11.16  | 5.00             |                      |
| DCA<br>DCA                        | 705.                      | 8.45           | 66.97          |                  |                      |
|                                   |                           |                |                |                  |                      |

INJECTOR

FUEL

LCX

DELTA P

110.

. INJECTOR DATA .

FLOH

11.16

66.97

AREA

2.08

VELOCITY

1130.27

138.75

TABLE 37. — SPLIT-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

| *******  | 有水泥泥 医甲苯苯苯苯磺胺 化铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁铁 |                       |
|--|---|-----------------------|
| <ul> <li>TURBOMACHI</li> </ul>                   | NERY PERFORMANCE DATA #                             |                       |
|  | ********  |                       |
|  | *******   | ****                  |
| 4 H2 BOOST TURBINE #                             | * H2 BOOST P  |                       |
|  | *******   | ****                  |
| EFFICIENCY (1/T) 0.885<br>EFFICIENCY (1/S) 0.703 | EFFICIENCY  | 0.765                 |
|  | HORSEPOHER  | 72.                   |
| SPEED (RPM) 33752. MEAN DIA (IN) 2.60            | SPEED (RPM)   | 33752.                |
| EFF AREA (IN2) 2.34                              | S SPEED   | 3046.                 |
| U/C (ACTUAL) 0.553                               | HEAD (FT)   | 2700.                 |
| MAX TIP SPEED 465.                               | DIA. (IN)   | 2.98                  |
| STAGES 1   | TIP SPEED<br>VOL. FLON                              | 439.                  |
| GAMMA 1.39                                       | HEAD COEF   | 1142.                 |
| PRESS RATIO (T/T) 1.01                           | FLOH COEF   | 0.450                 |
| PRESS RATIO (T/S) 1.02                           | TEUM COEF   | 0.201                 |
| HORSEPOWER 72.                                   |   |                       |
| EXIT MACH NUMBER 0.07                            |   |                       |
| SPECIFIC SPEED 112.18                            |   |                       |
| SPECIFIC DIAMETER 0.77                           |   |                       |
|  |   |                       |
| 斯森伊莱州州 机机械 化水油 电水水                               | ****  |                       |
| # H2 TURBINE #                                   | # H2 PUMP   | •                     |
| *********  | ********  |                       |
|  | STAGE ONE   | STAGE THO STAGE THREE |
| EECTOTION  | 新疆级数据和证券  | *******               |
| EFFICIENCY (T/T) 0.856                           | EFFICIENCY 0.704                                    |                       |
| EFFICIENCY (T/S) 0.832                           | HORSEPOHER 1824.                                    | 511. 505.             |
| SPEED (RPM) 107143.                              | SPEED (RPM) 107143.                                 | 107143. 107143.       |
| HORSEPOHER 2839.<br>MEAN DIA. (IN) 3 61          | SS SPEED 11888.                                     |                       |
|  | S_SPEED 897.  | 976. 979.             |
| EFF AREA (IN2) 0.34<br>U/C (ACTUAL) 0.548        | HEAD (FT) 63208.                                    |                       |
|  | DIA. (IN) 4.17                                      |                       |
| MAX TIP SPEED 1771. STAGES 2                     | TIP SPEED 1950.                                     | 1491. 1491.           |
| GAHMA 1.39                                       | VOL. FLOW 1114,<br>HEAD COEF 0.535                  | 550. 544.             |
| PRESS RATIO (T/T) 1.77                           | - · · · · · · · · · · · · · · · · · · ·             | 0.511 0.505           |
| PRESS RATIO (T/S) 1.80                           | FLOW COEF 0.104<br>DIAMETER RATIO 0.364             |                       |
| EXIT MACH NUMBER 0.15                            | BEARING DN 3.00E+06                                 |                       |
| SPECIFIC SPEED 41.14                             | SHAFT DIAMETER 28.00                                |                       |
| SPECIFIC DIAMETER 1.92                           | 28.00   |                       |
|  |   |                       |
| 医甲卡氏试验 医阴茎状状状 化自然放弃法                             | 有用有品质的有效的现在分  | ***                   |
| # 02 BOOST TURBINE #                             | # 02 BOOST PU                                       | HP =                  |
| <b>美国用收款货票款贷款收益金额股份金额</b>                        | ********  | ****                  |
| EFFICIENCY (T/T) 0.876                           | EFFICIENCY  | 0.764                 |
| EFFICIENCY (T/S) 0.812                           | HORSEPONER  | 39.                   |
| SPEED (RPM) 9026.                                | SPEED (RPM)   | 9026.                 |
| MEAN DIA (IN) 7.12<br>왕조 (INC) 3.24              | S SPEED   | 3026.                 |
|  | HEAD (FT)   | 242.                  |
| U/C (ACTUAL) 0.553 MAX TIP SPEED 301.            | DIA. (IN)   | 3.34                  |
| STAGES 1   | TIP SPEED   | 132.                  |
| GAMMA 1.39                                       | VOL. FLON   | 423.                  |
| PRESS RATIO (T/T) 1.01                           | HEAD COEF<br>FLOH COEF                              | 0.450                 |
| PRESS RATIO (T/S) 1.01                           | ream coer   | 0.200                 |
| HORSEPOWER 39.                                   |   |                       |
| EXIT MACH NUMBER 0.03                            |   |                       |
| SPECIFIC SPEED 53.61                             |   |                       |
| SPECIFIC DIAMETER 1.53                           |   |                       |
|  |   |                       |
| 有非常有效的现在分词                                       | ******  |                       |
| # 02 TURBINE #                                   | # 02 PUMP #   |                       |
| *********  | ******  |                       |
| EFFICIENCY (T/T) 0.857                           |   | 0.760                 |
| EFFICIENCY (T/S) 0.833                           | HORSEPOMER  | 721.                  |
| SPEED (RPM) 51439.                               | SPEED (RPM)   | 51439.                |
| HORSEPOWER 721.                                  | SS SPEED  | 20673.                |
| MEAN DIA (IN) 3.61<br>EFF AREA (IN2) 0.44        | 2 SPEED   | 1921.                 |
|  | HEAD (FT)<br>DIA. (IN)                              | 4492.                 |
| U/C (ACTUAL) 0.522 MAX TIP SPEED 858.            |   | 2.58                  |
|  | TIP SPEED   | 579.                  |
| •  | VOL. FLOW   | 420.                  |
| PRESS RATIO (T/T) 1.14                           | HEAD COEF   | 0.431                 |
| PRESS RATIO (1/5) 1.15                           | FLOH COEF   | 0.159                 |
| EXIT MACH NUMBER 0.07                            | DIAMETER RATIO BEARING ON 1.                        | 0.685                 |
| SPECIFIC SPEED 44.05                             | SHAFT DIAMETER                                      |                       |
| SPECIFIC DIAMETER 1.72                           | See I DIANCIEK                                      | 28.00                 |
| · -  |   |                       |

TABLE 38. — SPLIT-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER)

ENGINE PERFORMANCE PARAMETERS

|   |                            |                | E PAKAMETER<br>******* |                                  |               |
|---|----------------------------|----------------|------------------------|----------------------------------|---------------|
|   | nca 005001                 | nr.            |                        | 1406.6                           |               |
|   | BER PRESSU                 |                |                        | 50000.                           |               |
|   | ENGINE THR<br>L ENGINE F   |                |                        | 104.18                           |               |
|   | VAC. ISP                   | CON MAIL       |                        | 480.0                            |               |
|   | AT AREA                    |                |                        | 17.36                            |               |
|   | LE AREA RA                 | TIO            |                        | 1000.0                           |               |
| NOZZ  | LE EXIT DI                 | AMETER         |                        | 148.69                           |               |
|   | NE HIXTURE                 | RATIO          |                        | 6.00                             |               |
| ETA   |                            |                |                        | 0.993                            |               |
|   | BER COOLAN<br>BER COOLAN   |                |                        | 448.<br>716.                     |               |
|   | LE/CHAMBER                 |                |                        | 19957.                           |               |
|   |                            | -              |                        |                                  |               |
|   |                            |                | CONDITIONS             |                                  |               |
|   |                            | ******         |                        |                                  |               |
|   |                            |                | NDITIONS *             |                                  |               |
| MOITATE   | PRESS                      |                |                        | ENTHALPY                         | DENSITY       |
| B.P. INLET  | 18.6                       | 37.4           | 14.90                  | -107.5<br>-103.0                 | 4.37<br>4.39  |
| B.P. EXIT   | 101.0                      | 38.5<br>38.5   | 14.90<br>14.90         | -103.6                           | 4.39          |
| PUMP INLET<br>1ST STAGE EXIT  | 101.0                      | 60.7           | 14.90                  | 3.1                              | 4.54          |
|   | 1940.5                     | 61.1           | 7.45                   | 3.0                              | 4.52          |
| JBV EXIT  | 1649.4                     | 63.7           | 7.45                   | 3.0                              | 4.32          |
| 2ND STAGE EXIT  | 3033.6                     | 72.5           | 7.45                   | 61.7                             | 4.61          |
|   | 4094.4                     | 84.2           | 7.45                   | 119.9                            | 4.67          |
| COOLANT INLET   | 4053.4                     | 84.6           | 7.45                   | 119.9                            | 4.65          |
| COOLANT EXIT  | 3605.8<br>3569.7<br>1658.4 | 800.5          | 7.45                   | 2798.8                           | 0.77<br>0.76  |
| TBV INLET   | 3569.7                     | 800.7          | 0.37<br>0.37           | 2798.8<br>2798.8                 | 0.37          |
| TBV EXIT<br>D2 TRB INLET  | 3569.7                     | 812.8<br>800.7 | 7.08                   | 2798.8                           | 0.76          |
|   | 3110.4                     | 778.1          | 7.08                   | 2708.6                           | 0.69          |
| H2 TRR INEFT  | 3110.4                     | 778.1          | 7.08                   | 2708.0                           | 0.69          |
| H2 TRB EXIT   | 1775.1                     | 688.3          | 7.08                   | 2361.8                           | 0.46          |
| H2 TRB DIFFUSER   | 1748.7                     | 688.4          | 7.08                   | 2361.8                           | 0.45          |
| H2 TRB EXIT<br>H2 TRB DIFFUSER<br>H2 BST TRB IN   | 1731.2                     | 688.4          | 7.08                   | 2361.8                           | 0.45          |
| HZ 821 (KB UU)  | 1/04.0                     | 685.9          | 7.08                   | 2352.2                           | 0.44          |
| H2 BST TRB DIFF D2 BST TRB IN D2 BST TRB OUT D2 BST TRB DIFF H2 TANK PRESS GOX HEAT EXCH IN | 1699.0                     | 686.0<br>686.1 | 7.08<br>7.08           | 2 <b>352.2</b><br>2352. <b>2</b> | 0.44          |
| UZ BSI IKB IM   | 1667.6                     | 684.7          | 7.08                   | 2347.1                           | 0.44          |
| D2 BST TRB DIFF   | 1666.7                     | 684.7          | 7.08                   | 2347.1                           | 0.43          |
| H2 TANK PRESS   | 18.6                       | 700.4          | 0.0171                 | 2369.7                           | 6.0056        |
| GOX HEAT EXCH IN  | 1658.4                     | 691.2          | 7.43                   | 2369.7                           | 0.43          |
| GOX HEAT EXCH OUT   | 1650.1                     | 690.4          | 7.43                   | 2366.9                           | 0.43          |
| HIXER HOT IN  |                            | 690.4          | 7.43                   | 2366.9                           | 0.43<br>4.32  |
| MIXER COLD IN   | 1649.4                     | 63.7<br>368.3  | 7.45<br>14.88          | 3.0<br>1183.6                    | 0.74          |
|   | 1567.6<br>1567.6           | 368.3          | 14.88                  | 1183.6                           | 0.74          |
|   | 1528.4                     | 368.3          | 14.88                  | 1183.4                           | 0.72          |
| CHAMBER INJ   | 1497.2                     | 368.4          | 14.88                  | 1183.6                           | 0.71          |
|   | 1406.6                     |                |                        |                                  |               |
|   | = 0VV                      | EN SYSTEM      | CONDITIONS             |                                  |               |
| STATION   | PRESS                      | TEMP           | FLOH                   | ENTHALPY                         | DENSITY       |
| B.P. INLET  | 16.0                       | 162.7          | 89.4                   | 61.1                             | 71.17         |
| B.P. EXIT   | 135.6                      | 163.2          | 89.4                   | 61.5                             | 71.20         |
| PUMP INLET  | 135.6                      | 163.2          | 89.4                   | 61.5                             | 71.20         |
| PUMP EXIT   | 2278.1                     | 172.6          | 89.4                   | 68.6                             | 71.71         |
| 02 TANK PRESS<br>OCV INLET  | 16.0                       | 400.0          | 0.151                  | 204.7<br>68.6                    | 0.12<br>71.67 |
|   | 1578.7                     | 172.7<br>175.3 | 89.3<br>89.3           | 68.4                             | 70.62         |
| OCV EXIT<br>CHAMBER INJ   | 1547.3                     | 175.4          | 89.3                   | 68.6                             | 70.57         |
| CHAMBER   | 1406.6                     | .,,,,          |                        |                                  |               |
|   |                            | VALVE DA       | .TA =                  |                                  |               |
|   | DELTA D                    | ADCA           | FLOM                   | * BYPASS                         |               |
| VALVE   | DELTA P                    | AREA<br>0.31   | 7.45                   | 50.00                            |               |
| TBV   | 291.<br>1911.              | 0.02           | 0.37                   | 5.00                             |               |
| IBV<br>FSOV   | 39.                        | 4.03           | 14.88                  | 2                                |               |
| OCV   | 677.                       | 0.61           | 89.29                  |                                  |               |
|   |                            | IN SECTOR      | DATA -                 |                                  |               |
|   | •                          | INJECTOR       | DATA *                 |                                  |               |
| INJECTOR  | DELTA P                    | AREA           | FLON                   | VELOCITY                         |               |
| FUEL  | 106.                       | 2.77           | 14.88                  | 1092.16                          |               |
| LOX   | 156.                       | 1.34           | 89.29                  | 135.89                           |               |
|   |                            |                |                        |                                  |               |

TABLE 38. — SPLIT-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                                 |               | HEEGEREEREEREEREEREEREEREEREEREEREEREEREE |                |                 |               |
|---------------------------------|---------------|---|----------------|-----------------|---------------|
|                                 |               | MINERT PERFORMANCE :                      |                |                 |               |
| *********                       |               |   |                |                 |               |
| # H2 BOOST TU                   | RBINE .       |   | H2 BOOST P     |                 |               |
| ********                        | ****          |   |                |                 |               |
| EFFICIENCY (T/T)                |               |   | CIENCY         | 0.765           |               |
| EFFICIENCY (T/S)                |               |   | EPOHER         | 96.             |               |
|                                 | 29253.        |   | D (RPM)        | 29253.          |               |
| MEAN DIA (IN)<br>EFF AREA (IN2) |               | S SPE                                     |                | 3044.           |               |
| U/C (ACTUAL)                    |               | HEAD<br>DIA.                              |                | 2705.<br>3.44   |               |
| MAX TIP SPEED                   | 464.          |   | SPEED          | 440.            |               |
| STAGES                          | 1             |   | FLON           | 1523.           |               |
| GAMMA                           | 1.39          | HEAD                                      | COEF           | 0.450           |               |
| PRESS RATIO (T/T)               |               | FLON                                      | COEF           | 0.201           |               |
| PRESS RATIO (T/S)               |               |   |                |                 |               |
| HORSEPOHER EXIT MACH NUMBER     | 96.<br>0.07   |   |                |                 |               |
| SPECIFIC SPEED                  |               |   |                |                 |               |
| SPECIFIC DIAMETER               |               |   |                |                 |               |
|                                 |               |   |                |                 |               |
| ********                        |               |   | *******        | •               |               |
| * H2 TURBINE                    |               |   | # H2 PUMP      |                 |               |
| *********                       | •             |   | *****          |                 |               |
|                                 |               |   |                |                 | STAGE THREE   |
| EFFICIENCY (T/T)                | 0.871         | EFFICIENCY                                | 0.729          |                 |               |
| EFFICIENCY (T/S)                |               |   |                |                 |               |
| SPEED (RPM)                     |               | SPEED (RPM)                               | 100000.        | 618.<br>100000. | 100000.       |
| HORSEPOHER                      | 3466.         | SS SPEED                                  | 12796.         |                 |               |
| MEAN DIA. (IN)                  |               | S SPEED                                   | 999.           | 1097.           | 1095.         |
| EFF AREA (IN2)                  |               | HEAD (FT)                                 | 60136.         | 33143.          | 32916.        |
| U/C (ACTUAL) MAX TIP SPEED      | 1715.         | DIA. (IN)<br>TIP SPEED                    | 4.39           | 3.33            |               |
| STAGES                          | 2             | VOL. FLOH                                 | 1917.<br>1472. | 1455.<br>726.   | 1455.<br>716. |
| GAMMA                           | 1.39          | HEAD COEF                                 | 0.527          | 0.504           |               |
| PRESS RATIO (T/T)               |               | FLOH COEF                                 | 0.110          |                 | ****          |
| PRESS RATIO (T/S)               | 1.79          | DIAMETER RATIO                            | 0.395          |                 |               |
| EXIT MACH NUMBER                | 0.16          | BEARING DH                                |                |                 |               |
| SPECIFIC SPEED                  |               | SHAFT DIAMETER                            | 30.00          |                 |               |
| SPECIFIC DIAMETER               | 1.73          |   |                |                 |               |
| ********                        | *****         |   | *****          |                 |               |
| # 02 BOOST TUR                  | BINE .        |   | 02 BOOST PU    |                 |               |
| *********                       |               |   |                |                 |               |
| EFFICIENCY (T/T)                |               | EFF1C                                     | IENCY          | 0.764           |               |
| EFFICIENCY (T/S)                |               |   | POMER          | 51.             |               |
| SPEED (RPM) MEAN DIA (IN)       |               |   | (RPM)          | 7816.           |               |
| MEAN DIA (IN)                   | 8.22<br>4.12  | \$ SPEI<br>HEAD                           |                | 3026.<br>242.   |               |
| U/C (ACTUAL)                    |               | DIA.                                      | (IN)           | 3.85            |               |
| MAX TIP SPEED                   | 309.          | TIP SI                                    |                | 132.            |               |
| STAGES                          | 1             | VOL. F                                    | FLON           | 564.            |               |
| GAMMA                           | 1.39          | HEAD (                                    |                | 0.450           |               |
| PRESS RATIO (T/T)               |               | FLON (                                    | COEF           | 0.200           |               |
| PRESS RATIO (T/S) HORSEPOWER    | 1.01<br>51.   |   |                |                 |               |
| EXIT MACH NUMBER                | 0.03          |   |                |                 |               |
| SPECIFIC SPEED                  | 52.65         |   |                |                 |               |
| SPECIFIC DIAMETER               | 1.56          |   |                |                 |               |
|                                 |               |   |                |                 |               |
| *********                       |               |   | ********       |                 |               |
| # 02 TURBINE #                  |               |   | 02 PUMP #      |                 |               |
| EFFICIENCY (T/T)                |               |   | ENCY           | 0.769           |               |
| EFFICIENCY (T/S)                |               |   | OMER           | 910.            |               |
| SPEED (RPM)                     | 43615.        | SPEED                                     | (RPM)          | 43615.          |               |
| HORSEPOHER                      | 910.          | SS SPE                                    | ED             | 20241.          |               |
| MEAN DIA (IN)                   |               | S SPEE                                    | D              | 1943.           |               |
| EFF AREA (IN2)                  |               | HEAD                                      | (FT)<br>(IN)   | 4300.           |               |
| U/C (ACTUAL) MAX TIP SPEED      | 0.468<br>756. |   |                | 2.97            |               |
| STAGES                          | 756.<br>2     | TIP SP<br>VOL. F                          |                | 565.            |               |
| GAMMA                           | 1.39          | VUL. P<br>HEAD O                          |                | 560.<br>0.434   |               |
| PRESS RATIO (T/T)               | 1.15          | FLOH C                                    |                | 0.454           |               |
| PRESS RATIO (T/S)               |               |   | ER RATIO       | 0.686           |               |
| EXIT MACH NUMBER                | 0.07          | BEAR IN                                   | IG DN 1        | .31E+06         |               |
| SPECIFIC SPEED                  |               | SHAFT                                     | DIAMETER       | 30.00           |               |
| SPECIFIC DIAMETER               | 1.57          |   |                |                 |               |
|                                 |               |   |                |                 |               |

#### TABLE 39. - DUAL-EXPANDER ENGINE - 7500 LBF THRUST (COPPER **GROOVED CHAMBER)**

FUEL

LOX

|  |                            |                | E PARAMETER    |                    |                 |
|--|----------------------------|----------------|----------------|--------------------|-----------------|
|  |                            |                |                |                    |                 |
|  | MBER PRESSU                |                |                | 1300.3             |                 |
|  | ENGINE THR<br>AL ENGINE F  |                |                | 7500.<br>15.63     |                 |
| DEL. VAC. ISP  |                            |                |                | 479.9              |                 |
|  | OAT AREA                   |                |                | 2.82               |                 |
|  | ZLE AREA RA                |                |                | 1000.0             |                 |
|  | ZLE EXIT DI<br>INE MIXTURE |                |                | 59.88<br>6.00      |                 |
|  | C*                         | , KAI 10       |                | 0.993              |                 |
|  | MBER COOLAN                | IT DP          |                | 407.               |                 |
|  | MBER COOLAN                |                |                | 439.               |                 |
|  | ZLE COOLAN<br>ZLE COOLAN   |                |                | 184.<br>524.       |                 |
|  | MBER Q (HYD                |                | LED)           | 3787.              |                 |
|  | ZLE Q (OXYG                |                |                | 2435.              |                 |
|  |                            |                | CONDITIONS     | ***                |                 |
|  |                            |                | NDITIONS .     | ENTUAL BY          | DELECT TV       |
| STATION<br>B.P. INLET  | PRESS<br>18.6              | TEMP<br>37.4   | FLOW<br>2.24   | ENTHALPY<br>-107.5 | DENS1TY<br>4.37 |
| B.P. EXIT  | 101.1                      | 38.5           | 2.24           | -103.0             | 4.39            |
| PUMP INLET   | 101.1                      | 38.5           | 2.24           | -103.0             | 4.39            |
| IST STAGE EXIT   |                            | 65.0           | 2.24           | 8.6<br>116.4       | 4.32<br>4.31    |
| PUMP EXIT<br>COOLANT INLET   | 3311.8<br>3278.7           | 89.8<br>90.0   | 2.24           | 116.4              | 4.30            |
| COOLANT EXIT   | 2871.6                     | 529.5          | 2.24           | 1809.9             | 0.91            |
| TBV INLET  | 2842.9                     | 529.6          | 0.11           | 1809.9             | 0.90            |
| TBV EXIT<br>H2 TRB INLET<br>H2 TRB EXIT                                    | 1448.4                     | 535.9          | 0.11           | 1809.9             | 0.48            |
| H2 TRB INLET   | 2842.9                     | 529.6<br>472.1 | 2.12<br>2.12   | 1809.9<br>1579.0   | 0.90<br>0.57    |
| M2 TRE EXII  | 1532.4                     | 472.1          | 2.12           | 1579.0             | 0.56            |
| H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT H2 BST TRB DIFF H2 TANK PRESS | 1484.6                     | 472.2          | 2.12           | 1579.0             | 0.56            |
| HZ BST TRB OUT   | 1463.1                     | 471.0          | 2.12           | 1574.2             | 0.55            |
| H2 BST TRB DIFF  | 1448.4                     | 471.1          | 2.12           | 1574.2<br>1586.0   | 0.54<br>0.0073  |
| FSOV INLET   | 18.6                       | 479.0          | 0.0037<br>2.23 | 1586.0             | 0.0073          |
| FSOV EXIT  | 1412.2                     | 474.4          | 2.23           | 1586.0             | 0.53            |
| CHAMBER INJ  | 1383.4                     | 474.5          | 2.23           | 1586.0             | 0.52            |
| CHAMBER  | 1300.3                     |                |                |                    |                 |
| HOITATE  | PACCE PACCE                | EN SYSTEM      | CONDITIONS     | *<br>ENTHALPY      | DENSITY         |
| B.P. INLET   | 16.0                       | 162.7          | 13.4           | 61.1               | 71.17           |
| B.P. EXIT  | 135.6                      | 163.2          | 13.4           | 61.5               | 71.20           |
| PUMP INLET   | 135.6<br>4749.6            | 163.2          | 13.4           | 61.5               | 71.20           |
| PUMP EXIT  | 4749.6                     | 187.8<br>188.0 | 13.4<br>13.4   | 78.7<br>78.7       | 71.57<br>71.50  |
| COOLANT INLET  | 4702.1<br>4518.5           | 711.9          | 13.4           | 260.2              | 17.66           |
| OTBY INLET   | 4518.5                     | 711.9          | 0.6            | 260.2              | 17.66           |
| OTBV EXIT  | 2194.9                     | 690.5          | 0.6            | 260.2              | 9.39            |
| 02 TRB INLET<br>02 TRB EXIT  | 4518.5                     | 711.9          | 11.5<br>11.5   | 260.2<br>240.1     | 17.66<br>11.77  |
| OZ IRB EXII  | 2397.7                     | 615.6<br>612.3 | 11.5           | 240.1              | 10.87           |
| OZ BST TRB IN  | 4518.5                     | 711.9          | 1 - 3          | 260.2              | 17.66           |
| 02 TRB DIFFUSER<br>02 BST TRB IN<br>02 BST TRB OUT                         | 4485.7                     | 697.0          | 1.3            | 256.1              | 18.01           |
| OZ BST TRB DIFF  | 4484.3                     | 697.0          | 1.3            | 256.1              | 18.00<br>18.00  |
| OBTV INLET OBTV EXIT   | 4484.3<br>2194.9           | 697.0<br>674.5 | 1.3            | 256.1<br>256.1     | 9.66            |
| MIXER  | 2194.9                     | 622.0          | 13.4           | 242.6              | 10.66           |
| 02 TANK PRESS  |                            | 572.9          | 0.016          | 242.6              | 0.08            |
| OCV INLET  | 2085.2                     | 620.2          | 13.4           | 242.6              | 10.18           |
| OCV EXIT   | 1459.6                     | 608.7          | 13.4<br>13.4   | 242.6<br>242.6     | 7.29<br>7.16    |
| CHAMBER INJ<br>CHAMBER   | 1430.6<br>1300.3           | 408.1          | 13.4           | 242.0              | 7.14            |
|  |                            | VALVE DA       | TA =           |                    |                 |
| VALVE  | DELTA P                    |                | FLOH           | % BYPASS           |                 |
| OTBV   | 2324.                      | 0.01           | 0.60           | 5.00<br>5.00       |                 |
| TBV<br>FSOV  | 1394.<br>36.               | 0.01<br>0.74   | 0.11<br>2.23   | 5.00               |                 |
| OBTV   | 2289.                      | 0.01           | 1.34           |                    |                 |
| ocv  | 626.                       |                | 13.39          |                    |                 |
|  | •                          | INJECTOR       | DATA #         |                    |                 |
| INJECTOR   | DELTA P                    | AREA           | FLOH           | VELOCITY           |                 |
| FIFE   | 98.                        |                |                | 1217.82            |                 |

0.51

0.66

2.23

1217.82 410.59

98. 145.

TABLE 39. — DUAL-EXPANDER ENGINE — 7500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                                     |                 | ******                       |                     |                |               |
|-------------------------------------|-----------------|------------------------------|---------------------|----------------|---------------|
|                                     |                 | HINERY PERFORMANCE           |                     |                |               |
| *********                           |                 | ************                 |                     |                |               |
| # H2 BOOST T                        |                 |                              |                     |                |               |
| - 12 00031 1                        |                 |                              | HC BOOST            |                |               |
| EFFICIENCY (T/T                     |                 |                              | CIENCY              | 0.76           | ς.            |
| EFFICIENCY (T/S                     | 0.368           |                              | EPO <del>LE</del> R | 14             |               |
| SPEED (RPM                          | 75548.          |                              | D (RPM)             |                |               |
| MEAN DIA (IN                        |                 | S SP                         |                     | 3043           |               |
| EFF AREA (IN2                       |                 | HEAD                         | (FT)                | 2708           |               |
| U/C (ACTUAL                         |                 | DIA.                         |                     | 1.3            | 5             |
| MAX TIP SPEED<br>STAGES             | 3 <b>9</b> 2.   |                              | SPEED               | 440            |               |
| GAMMA                               | 1<br>1.40       |                              | FLON                | 229.           |               |
| PRESS RATIO (T/T)                   |                 |                              | කණ<br>කණ            | 0.450          |               |
| PRESS RATIO (T/S                    |                 | , con                        |                     | 0.20           | •             |
| HORSEPOHER                          | 14.             |                              |                     |                |               |
| EXIT MACH NUMBER                    | 0.12            |                              |                     |                |               |
| SPECIFIC SPEED                      | 143.69          |                              |                     |                |               |
| SPECIFIC DIAMETER                   | 0.52            |                              |                     |                |               |
|                                     |                 |                              |                     |                |               |
|                                     |                 |                              | ******              |                |               |
| * H2 TURBINE                        |                 |                              | # H2 PUM            |                |               |
|                                     | •               |                              | ******              |                |               |
|                                     |                 |                              | STAGE ON            |                | AGE THO       |
| EFFICIENCY (T/T)                    | 0.781           | EFFICIENCY                   | 0.623               |                | *******       |
| EFFICIENCY (T/S)                    |                 | HORSEPONER                   | 353.                |                | 0.628<br>341. |
|                                     | 187500.         | SPEED (RPM)                  | 187500.             |                | 87500.        |
| HORSEPOHER                          | 694.            | SS SPEED                     | 9288.               |                | 07300.        |
| MEAN DIA. (IN)                      | 2.22            | S SPEED                      | 805.                |                | 822.          |
| EFF AREA (IN2)                      |                 | HEAD (FT)                    | 54135.              |                | 52690.        |
| U/C (ACTUAL)                        | 0.535           | DIA. (IN)                    | 2.24                |                | 2.24          |
| MAX TIP SPEED                       | 1890.           | TIP SPEED                    | 1834.               |                | 1834.         |
| STAGES                              | 1               | VOL. FLOH                    | 232.                |                | 233.          |
| GANNA                               | 1.40            | HEAD COEF                    | 0.518               |                | 0.504         |
| PRESS RATIO (T/T) PRESS RATIO (T/S) |                 | FLON COEF                    | 0.097               |                |               |
| EXIT HACH NUMBER                    |                 | DIAMETER RATIO<br>BEARING DN |                     |                |               |
| SPECIFIC SPEED                      | 32.34           | SHAFT DIAMETER               |                     |                |               |
| SPECIFIC DIAMETER                   |                 | SHAFT DIAMETER               | 16.00               |                |               |
|                                     |                 |                              |                     |                |               |
| *******                             | ****            |                              | ******              |                |               |
| # 02 BOOST TU                       |                 |                              | CC BOOST I          | PUMP #         |               |
|                                     |                 |                              | ********            | ****           |               |
| EFFICIENCY (T/T)                    |                 |                              | IE-CY               | 0.764          |               |
| EFFICIENCY (T/S) SPEED (RPM)        | 0.752<br>20187. |                              | POMER               | 8.             |               |
| HEAN DIA (IN)                       |                 | S SPE                        | (RPM)               |                |               |
| EFF AREA (IN2)                      |                 | HEAD                         |                     | 3026.<br>242.  |               |
| U/C (ACTUAL)                        |                 | DIA.                         | (IN)                |                |               |
| MAX TIP SPEED                       | 263.            |                              | PEED                | 132.           |               |
| STAGES                              | ı               | VOL.                         | FLOH                | 85.            |               |
| GAMMA                               | 1.63            | HEAD                         | COEF                | 0.450          |               |
| PRESS RATIO (T/T)                   |                 | FLOR                         | COEF                | 0.200          |               |
| PRESS RATIO (T/S)                   |                 |                              |                     |                |               |
| HORSEPONER EXIT MACH HUMBER         | 8.              |                              |                     |                |               |
| SPECIFIC SPEED                      | 0.02<br>41.09   |                              |                     |                |               |
| SPECIFIC DIAMETER                   | 1.88            |                              |                     |                |               |
| a con to other len                  | 1.00            |                              |                     |                |               |
| ********                            |                 |                              |                     |                |               |
| # 02 TURBINE #                      |                 |                              | 02 PUMP             |                |               |
| **********                          |                 |                              |                     | -              |               |
|                                     | 0.811           | EFF IC                       | IE-CY               | 0.693          |               |
| EFFICIENCY (T/S)                    | 0.697           | HORSE                        | POMER               | 326.           |               |
| SPEED (RPM)                         |                 |                              | (RPM)               | 154919.        |               |
| HORSEPOHER                          | 326.            | SS SPE                       |                     | 27838.         |               |
| MEAN DIA (IN)                       |                 | S SPEE                       |                     | 1502.          |               |
| EFF AREA (IN2)                      |                 |                              | (FT)                | 9282.          |               |
| U/C (ACTUAL)                        |                 | DIA.                         | (IN)                | 1.22           |               |
| MAX TIP SPEED<br>STAGES             | 640.<br>1       | TIP SF                       |                     | 826.           |               |
| GAMMA                               | 1.63            | VOL. F                       |                     | 84.            |               |
| PRESS RATIO (T/T)                   | 1.88            | HEAD C                       |                     | 0.438          |               |
| PRESS RATIO (T/S)                   |                 |                              | ER RATIO            | 0.139<br>0.669 |               |
| EXIT MACH NUMBER                    | 0.34            |                              |                     | 1.558.06       |               |
| SPECIFIC SPEED                      | 85.40           |                              | DIAMETER            |                |               |
| SPECIFIC DIAMETER                   |                 |                              |                     |                |               |
|                                     | -               |                              |                     |                |               |

TABLE 40. - DUAL-EXPANDER ENGINE - 15,000 LBF THRUST (COPPER GROOVED CHAMBER)

INJECTOR

FUEL

LOX

|  | ENGINE PE                   |                | PARAMETER     |                    |                 |
|--|-----------------------------|----------------|---------------|--------------------|-----------------|
| ••   |                             |                |               |                    |                 |
|  | BER PRESSUE                 |                |               | 1140.6<br>15000.   |                 |
|  | ENGINE THRI<br>L ENGINE FL  |                |               | 31.24              |                 |
|  | VAC. ISP                    |                |               | 479.9<br>6.41      |                 |
|  | MAT AREA<br>"LE AREA RA"    | 110            |               | 1000.0             |                 |
| NO22   | LE EXIT DIA                 | METER          |               | 90.37<br>6.00      |                 |
| ENG1<br>ETA  | NE MIXTURE<br>C#            | RAITU          |               | 0.993              |                 |
| CHW  | BER COOLAN                  |                |               | 368.<br>356.       |                 |
|  | OBER COOLAN<br>PLE COOLAN   |                |               | 203.               |                 |
| HOZZ   | LE COOLAN                   | T DT           |               | 404.<br>6150.      |                 |
|  | GBER Q (HYDI<br>ZLE Q (OXYG |                |               | 3986.              |                 |
|  | ENGINE                      |                | CONDITIONS    | ***                |                 |
|  |                             |                | DITIONS .     |                    |                 |
| STATION  | PRESS<br>18.6               | TEIP<br>37.4   | FLOH<br>4.47  | ENTHALPY<br>-107.5 | DENSITY<br>4.37 |
| B.P. IMLET<br>B.P. EXIT  | 100.8                       | 38.5           | 4.47          | -103.0             | 4.39            |
| PUMP INLET   | 100.8                       | 38.5           | 4.47          | ~103.0<br>-26.5    | 4.39<br>4.45    |
| IST STAGE EXIT PUMP EXIT                                       | 1374.1<br>2646.2            | 55.4<br>71.6   | 4.47<br>4.47  | 49.2               | 4.50            |
| COOLANT INLET  | 2619.7                      | 71.9           | 4.47          | 49.2               | 4.49            |
| COOLANT EXIT   | 2619.7<br>2252.2<br>2229.7  | 428.0<br>428.1 | 4.47<br>0.22  | 1423.6<br>1423.6   | 0.87            |
| TBV INLET TBV EXIT   | 1270.6                      | 431.0          | 0.22          | 1423.6             | 0.52            |
| H2 TRB INLET<br>H2 TRB EXIT                                    | 2229.7                      | 428.1          | 4.25<br>4.25  | 1423.6<br>1263.4   | 0.88<br>0.61    |
| H2 TRB EXIT  | 1353.4                      | 389.1<br>389.2 | 4.25          | 1263.4             | 0.60            |
| H2 TRB DIFFUSER<br>H2 BST TRB IN<br>H2 BST TRB OUT             | 1306.7                      | 389.2<br>388.1 | 4.25          | 1263.4             | 0.60<br>0.59    |
|  |                             | 388.1<br>388.1 | 4.25<br>4.25  | 1258.6<br>1258.6   | 0.58            |
| H2 TANK PRESS  | 18.6                        | 392.3          | 0.0092        | 1266.9             | 0.0089          |
| FSOV INLET   | 1270.6                      | 390.2<br>390.3 | 4.47<br>4.47  | 1266.9<br>1266.9   | 0.58<br>0.56    |
| H2 BST TRB DIFF H2 TANK PRESS FSOV INLET FSOV EXIT CHARBER INJ | 1213.6                      | 390.3          |               | 1266.9             | 0.55            |
| CHAMBER  | 1140.6                      |                |               |                    |                 |
|  | * 0XYG                      | EN SYSTEM      | CONDITION     | ENTHALPY           | DEMSITY         |
| STATION<br>B.P. INLET  | 16.0                        | 162.7          | 26.8          | 61.1               | 71.17           |
| B.P. EXIT  | 135.6                       | 163.2          | 26.8          | 61.5               | 71.20<br>71.20  |
| PUMP INLET<br>PUMP EXIT  | 135.6<br>4682.5             | 163.2<br>185.7 | 26.8<br>26.8  | 61.5<br>77.7       | 71.82           |
| COOLANT INLET  | 4635.7                      | 185.9          | 26.8          | 77.7               | 71.75           |
| COOLANT EXIT   | 4433.1                      | 590.2<br>590.2 | 26.8<br>1.2   | 226.3<br>226.3     | 21.91<br>21.91  |
| OTBV INLET   | 4433.1<br>1925.5            | 554.6          | 1.2           | 226.3              | 10.85           |
| 02 TRB INLET   | 4433.1                      | 590.2          | 22.9          | 226.3<br>207.3     | 21.91<br>14.35  |
| O2 TRB EXIT  | 2131.5                      | 491.8<br>486.6 | 22.9<br>22.9  | 207.3              | 15.12           |
| 02 TRB DIFFUSER<br>02 BST TRB IN                               | 4433.1                      | 590.2          | 2.7           | 226.3              | 21.91           |
| 02 BST TRB OUT   | 4394.8                      | 576.2<br>576.2 | 2.7<br>2.7    | 222.2<br>222.2     | 22.45<br>22.44  |
| 02 BST TRB DIFF<br>OBTV INLET                                  | 4393.2                      | 576.2          | 2.7           | 222.2              | 22.44           |
| TIX3 VTBO  | 1925.5                      | 539.7          | 2.7           | 222.2<br>209.6     | 11.26<br>12.76  |
| MIXER<br>02 TANK PRESS   | 1925.5<br>16.0              | 494.9<br>422.3 | 26.8<br>0.043 | 209.6              | 0.11            |
| OCV INLET  | 1829.3                      | 492.3          | 26.8          | 209.6              | 12.19           |
| OCV EXIT   | 1280.5<br>1255.0            | 476.2<br>475.3 | 26.8<br>26.8  | 209.6<br>209.6     | 8.77<br>8.60    |
| CHAMBER INJ<br>CHAMBER   | 1140.6                      | 4.5.0          | 2375          |                    |                 |
|  |                             | • VALVE DA     | ATA =         |                    |                 |
| VALVE  | DELTA P                     |                | FLON          | % BYPASS           |                 |
| OTBV   | 2508.<br>959.               | 0.01<br>0.01   | 1.21<br>0.22  | 5.00<br>5.00       |                 |
| TBV<br>FSOV  | 32.                         | 1.54           | 4.47          |                    |                 |
| OBTV   | 2468.                       |                | 2.68<br>26.79 |                    |                 |
| ocv  | 549.                        |                |               |                    |                 |
|  | •                           | INJECTOR       | DATA #        | ven oce try        |                 |

AREA

1.06

DELTA P

86.

127.

FLOH 4.47 26.79

VELOCITY

TABLE 40. — DUAL-EXPANDER ENGINE — 15,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|   | ********          | ~ | ******                       |               |         |
|---|-------------------|---|------------------------------|---------------|---------|
|   |                   | HINERY PERFORMANCE                      |                              |               |         |
|   |                   |   |                              |               |         |
| **********                                      |                   |   |                              |               |         |
| • H2 BOOST 1                                    |                   |   | * H2 BOOST                   | -             |         |
| EFFICIENCY (1/1                                 |                   |   | *******                      |               | _       |
| EFFICIENCY (T/S                                 |                   |   | ICIENCY<br>SEPOHER           | 0.76          |         |
| SPEED (RPH                                      |                   |   | ED (RPM)                     |               | •       |
| MEAN DIA CIN                                    |                   |   | PEED                         | 3045          |         |
| EFF AREA (IN2                                   | 1.73              | HEA                                     | 0 (FT)                       |               |         |
|   | 0.553             |   | . (IN)                       | 1.8           | ,       |
| MAX TIP SPEED                                   |                   |   | SPEED                        | 439           | -       |
| STAGES<br>GAMMA                                 | 1<br>1.38         |   | . FLOW                       | 458           | •       |
| PRESS RATIO (T/T                                |                   |   | COEF                         | 0.450         |         |
| PRESS RATIO (T/S                                |                   | 7.00                                    | COEF                         | 0.20          | ı       |
| HORSEPOHER                                      | 29.               |   |                              |               |         |
| EXIT MACH MUMBER                                |                   |   |                              |               |         |
| SPECIFIC SPEED                                  |                   |   |                              |               |         |
| SPECIFIC DIMETER                                | R 0.52            |   |                              |               |         |
|   |                   |   |                              |               |         |
| # H2 TURBINE                                    |                   |   | * H2 PUM                     |               |         |
| *********                                       |                   |   | ******                       |               |         |
|   |                   |   | STAGE DN                     |               | AGE THO |
|   |                   |   | ******                       |               | ******  |
| EFFICIENCY (T/T                                 |                   | <b>EFFICIENCY</b>                       | 0.695                        |               | 0.695   |
| EFFICIENCY (T/S<br>SPEED (RPM                   |                   | HORSEPOHER                              | 485.                         |               | 479.    |
| HORSEPOHER                                      | ) 136363.<br>964. | SPEED (RPM)<br>SS SPEED                 | 136363.<br><del>9</del> 571. |               | 36363.  |
| MEAN DIA. (IN                                   |                   | S SPEED                                 | 999.                         |               | 1001.   |
| EFF AREA (IN2                                   |                   | HEAD (FT)                               | 41375.                       |               | 40897.  |
|   | 0.553             | DIA. (IN)                               | 2.71                         |               | 2.71    |
| HAX TIP SPEED                                   | 1653.             | TIP SPEED                               | 1612.                        |               | 1612.   |
| STAGES  | 1                 | VOL. FLOW                               | 452.                         |               | 446.    |
| GAMMA PRESS RATIO (T/T)                         | 1.38              | HEAD COEF<br>FLOW COEF                  | 0.512                        |               | 0.506   |
| PRESS RATIO (T/S)                               |                   | DIAMETER RATIO                          | 0.110<br>0.381               |               |         |
| EXIT MACH NUMBER                                |                   | BEARING DN                              |                              |               |         |
| SPECIFIC SPEED                                  | 43.19             | SHAFT DIAMETER                          |                              |               |         |
| SPECIFIC DIMETER                                | 1.81              |   |                              |               |         |
| *********                                       |                   |   |                              |               |         |
| # 02 BOOST TU                                   |                   |   | O2 BOOST #                   |               |         |
| **********                                      |                   |   | U2 BUUSI I                   |               |         |
| EFFICIENCY (T/T)                                | 0.808             |   | CIENCY                       | 0.764         |         |
| EFFICIENCY (T/S)                                |                   | HORSI                                   | EPOHER                       | 15.           |         |
|   | 14271.            |   | D (RPM)                      | 14271.        |         |
| HEAN DIA (IN)<br>EFF: AREA (IN2)                |                   | S SPI                                   |                              | 3026.         |         |
| EFF-AREA (IN2) U/C (ACTUAL)                     |                   | HEAD<br>DIA.                            | (FT)<br>(IN)                 |               |         |
| MAX TIP SPEED                                   | 261.              |   | SPEED                        | 2.11<br>132.  |         |
| STAGES  | 1                 |   | FLOH                         | 169.          |         |
| GANNA   | 1.78              |   | COEF                         | 0.450         |         |
| PRESS RATIO (T/T)                               |                   | FLOH                                    | COEF                         | 0.200         |         |
| PRESS RATIO (T/S)<br>HORSEPOHER                 | 1.01<br>15.       |   |                              |               |         |
| EXIT MACH NUMBER                                |                   |   |                              |               |         |
| SPECIFIC SPEED                                  | 38.28             |   |                              |               |         |
| SPECIFIC DIAMETER                               | 2.02              |   |                              |               |         |
|   |                   |   |                              |               |         |
| **********                                      |                   |   | ******                       |               |         |
| # 02 TURBINE                                    |                   |   | # 02 PUMP                    |               |         |
| EFFICIENCY (T/T)                                |                   | FFEIC                                   | HARRESHEE<br>HENCY           | 0.720         |         |
| EFFICIENCY (T/S)                                | 0.718             | HORSE                                   | POMER                        | 618.          |         |
| SPEED (RPM)                                     | 107453.           | SPEED                                   | (RPH)                        | 107453.       |         |
| HORSEPOHER                                      | 618.              |   | EED                          | 27313.        |         |
| MEAN DIA (IN)                                   | 1.15              | S SPE                                   |                              | 1492.         |         |
| MEAN DIA (IN)<br>EFF AREA (IN2)<br>U/C (ACTUAL) | 0.21              | HEAD                                    | (FT)<br>(IN)                 | 9114.         |         |
| U/C (ACTUAL) MAX TIP SPEED                      |                   | DIA.                                    |                              |               |         |
| STAGES  | 619.<br>1         | TIP S<br>VOL.                           |                              | 807.          |         |
| GAMMA   | 1.78              | VUL.<br>HEAD                            |                              | 168.<br>0.450 |         |
| PRESS RATIO (T/T)                               |                   |   | COEF                         | 0.450         |         |
| PRESS RATIO (T/S)                               | 2.39              |   | TER RATIO                    |               |         |
| EXIT MACH NUMBER                                | 0.35              |   | NG DN                        |               |         |
| SPECIFIC SPEED                                  | 83.84             | SHAFT                                   | DIAMETER                     | 14.00         |         |
| SPECIFIC DIAMETER                               | 0.98              |   |                              |               |         |

## TABLE 41. — DUAL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER)

| ENGINE | PERFORMANCE | PARAMETERS |
|--------|-------------|------------|
| ****** |             | ********** |

| CHAMBER PRESSURE            | 1108.7 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 25000. |
| TOTAL ENGINE FLON RATE      | 52.10  |
| DEL, VAC. ISP               | 479.9  |
| THROAT AREA                 | 11.00  |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 118.33 |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C#                      | 0.993  |
| CHAMBER COOLANT DP          | 308.   |
| CHAMBER COOLANT DT          | 317.   |
| NOZZLE COOLANT DP           | 222.   |
| NOZZLE COOLANT DT           | 351.   |
| CHAMBER Q (HYDROGEN COOLED) | 9095.  |
| NOZZLE Q (OXYGEN COOLED)    | 5893.  |
| NUZZLE U TUKTGEN COCCEDI    | 20.00  |

## ENGINE STATION CONDITIONS

|                 | * FUEL | SYSTEM CO | MOITIONS # |          |   |
|-----------------|--------|-----------|------------|----------|---|
| STATION         | PRESS  | TEMP      | FLON       | ENTHALPY | DENSITY                                 |
| B.P. INLET      | 18.6   | 37.4      | 7.46       | -107.5   | 4.57                                    |
| B.P. EXIT       | 100.5  | 38.5      | 7.46       | -103.0   | 4.59                                    |
| PUMP INLET      | 100.5  | 38.5      | 7.46       | -103.0   | 4.39                                    |
| IST STAGE EXIT  | 1234.6 | 51.8      | 7.46       | -39.5    | 4.50                                    |
| PUMP EXIT       | 2386.6 | 64.6      | 7.46       | 23.9     | 4.59                                    |
| COOLANT INLET   | 2362.7 | 64.8      | 7.46       | 23.9     | 4.57                                    |
| COOLANT EXIT    | 2055.1 | 382.3     | 7.46       | 1243.2   | 0.91                                    |
| TBV INLET       | 2034.6 | 382.4     | 0.37       | 1243.2   | 0.91                                    |
| TBV EXIT        | 1235.1 | 384.2     | 0.37       | 1243.2   | 0.57                                    |
| H2 TRB INLET    | 2034.6 | 382.4     | 7.09       | 1243.2   | 0.91                                    |
| H2 TRB EXIT     | 1321.6 | 350.2     | 7.09       | 1109.6   | 0.67                                    |
| H2 TRB DIFFUSER | 1282.5 | 350.2     | 7.09       | 1109.6   | 0.65                                    |
| H2 BST TRB IN   | 1269.6 | 350.2     | 7.09       | 1109.6   | 0.65                                    |
| H2 BST TRB OUT  | 1248.5 | 369.1     | 7.09       | 1104.8   | 0.63                                    |
| H2 BST TRB DIFF | 1235.1 | 349.1     | 7.09       | 1104.8   | 0.63                                    |
| H2 TANK PRESS   | 18.6   | 351.6     | 0.0173     | 1111.7   | 0.0100                                  |
|                 | 1235.1 | 350.8     | 7.44       | 1111.7   | 0.62                                    |
| FSOV INLET      | 1204.2 | 350.9     | 7.44       | 1111.7   | 0.61                                    |
| FSOV EXIT       |        | 350.9     | 7.44       | 1111.7   | 0.60                                    |
| CHAMBER INJ     | 1179.7 | 350.7     | ,.44       |          | • |
| CHAMBER         | 1108.7 |           |            |          |   |

|                 | * OXYE | EN SYSTEM | CONDITIONS | S #      |         |
|-----------------|--------|-----------|------------|----------|---------|
| STATION         | PRESS  | TEMP      | FLOH       | ENTHALPY | DENSITY |
| B.P. INLET      | 16.0   | 162.7     | 44.7       | 61.1     | 71.17   |
| B.P. EXIT       | 135.6  | 163.2     | 44.7       | 61.5     | 71.20   |
| PUMP INLET      | 135.6  | 163.2     | 44.7       | 61.5     | 71.20   |
| PUMP EXIT       | 4859.1 | 185.5     | 44.7       | 77.9     | 71.99   |
| COOLANT INLET   | 4810.5 | 185.7     | 44.7       | 77.9     | 71.92   |
| COOLANT EXIT    | 4589.0 | 537.0     | 44.7       | 209.7    | 25.58   |
| OTBY INLET      | 4589.0 | 537.0     | 2.0        | 209.7    | 25.58   |
| OTBV EXIT       | 1871.0 | 495.6     | 2.0        | 209.7    | 12.43   |
| OZ TRB INLET    | 4589.0 | 537.0     | 38.3       | 209.7    | 25.58   |
| OZ TRB EXIT     | 2078.1 | 436.8     | 38.3       | 190.4    | 17.06   |
| 02 TRB DIFFUSER | 1871.0 | 430.5     | 38.3       | 190.4    | 15.62   |
| OZ BST TRB IN   | 4589.0 | 537.0     | 4.5        | 209.7    | 25.58   |
| 02 BST TRB OUT  | 4547.3 | 523.7     | 4.5        | 205.6    | 26.34   |
| OZ BST TRB DIFF | 4545.7 | 523.7     | 4.5        | 205.6    | 26.33   |
| OBTY INLET      | 4545.7 | 523.7     | 4.5        | 205.6    | 26.33   |
| OBTV EXIT       | 1871.0 | 479.4     | 4.5        | 205.6    | 13.05   |
| MIXER           | 1871.0 | 437.7     | 44.7       | 192.8    | 15.15   |
| 02 TANK PRESS   | 16.0   | 345.2     | 0.087      | 192.8    | 0.14    |
| OCV INLET       | 1777.5 | 434.7     | 44.7       | 192.8    | 14.49   |
| OCV EXIT        | 1244.2 | 415.1     | 44.7       | 192.B    | 10.50   |
| CHAMBER INJ     | 1219.5 | 414.0     | 44.7       | 192.8    | 10.31   |
| CHAMBER         | 1108.7 |           |            |          |         |

#### . VALVE DATA .

| VALVE<br>OTBV<br>TBV<br>FSOV<br>OBTV | DELTA P<br>2718.<br>799.<br>31.<br>2675. | AREA<br>0.02<br>0.03<br>2.50<br>0.04 | FLON<br>2.01<br>0.37<br>7.44<br>4.47 | % BYPASS<br>5.00<br>5.00 |
|--------------------------------------|--|--------------------------------------|--------------------------------------|--------------------------|
| FSOV                                 | 31.                                      | 2.50                                 | 7.44                                 | 5.00                     |

#### \* INJECTOR DATA \*

| INJECTOR | DELTA P | AREA | FLOH  | VELOC1TY |
|----------|---------|------|-------|----------|
| FUEL     | 84.     | 1.72 | 7.44  | 1043.94  |
| LOX      | 123.    | l.98 | 44.66 | 315.55   |

TABLE 41. — DUAL-EXPANDER ENGINE — 25,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                                     |               | HENERY PERFORMANCE           |                       |                 |
|-------------------------------------|---------------|------------------------------|-----------------------|-----------------|
|                                     |               | ************                 |                       |                 |
| *********                           |               | •                            | ********              |                 |
| # H2 BOOST TI                       |               |                              | H2 BOOST              |                 |
| EFFICIENCY (T/T                     |               |                              | CIENCY                |                 |
| EFFICIENCY (T/S                     | ) 0.443       |                              | EPOMER                | 0.766<br>48.    |
|                                     | 1 41232.      |                              | D (RPM)               |                 |
| MEAN DIA (IN<br>EFF AREA (IN2)      |               | S SP                         |                       | 3049.           |
| U/C (ACTUAL)                        |               |                              | (FT)                  |                 |
| MAX TIP SPEED                       | 376.          | DIA.                         | (IN)<br>SPEED         | 2.44<br>439.    |
| STAGES                              | 1             |                              | FLON                  | 763.            |
| GAMMA                               | 1.36          |                              | COEF                  | 0.450           |
| PRESS RATIO (T/T) PRESS RATIO (T/S) |               | FLOW                         | COEF                  | 0.201           |
| HORSEPOHER                          | ) 1.03<br>48. |                              |                       |                 |
| EXIT MACH NUMBER                    | 0.13          |                              |                       |                 |
| SPECIFIC SPEED                      |               |                              |                       |                 |
| SPECIFIC DIAMETER                   | 0.52          |                              |                       |                 |
| *******                             |               |                              |                       |                 |
| # H2 TURBINE                        | -             |                              | # H2 PUM              |                 |
| ******                              |               |                              | ******                |                 |
|                                     |               |                              | STAGE ON              | E STAGE TWO     |
| EFFICIENCY (T/T)                    | 0 070         | FFFIGIEN                     | *******               |                 |
| EFFICIENCY (T/S)                    |               | EFFICIENCY<br>HORSEPONER     | 0.740<br><b>6</b> 70. |                 |
|                                     | 125000.       | SPEED (RPM)                  | 125000.               |                 |
|                                     | 1340.         | SS SPEED                     | 11364.                | 123000.         |
| MEAN DIA. (IN)<br>EFF AREA (IN2)    | 2.62          | S SPEED                      | 1290.                 |                 |
| U/C (ACTUAL)                        |               | HEAD (FT)<br>Dia. (In)       | 36570.                |                 |
| MAX TIP SPEED                       | 1549.         | TIP SPEED                    | 2.85<br>1556.         |                 |
| STAGES                              | 1             | VOL. FLON                    | 744.                  | 730.            |
| GAMMA                               | 1.36          | HEAD COEF                    | 0.486                 |                 |
| PRESS RATIO (T/T) PRESS RATIO (T/S) |               | FLOW COEF                    | 0.128                 |                 |
| EXIT MACH NUMBER                    | 0.23          | DIAMETER RATIO<br>BEARING DN |                       |                 |
| SPECIFIC SPEED                      | 58.33         | SHAFT DIAMETER               |                       |                 |
| SPECIFIC DIAMETER                   | 1.41          |                              |                       |                 |
| *****                               | *****         |                              |                       |                 |
| # 02 BOOST TUR                      |               |                              | 02 BOOST P            |                 |
| ******                              |               |                              | *******               |                 |
| EFFICIENCY (T/T)                    | 0.844         | EFF1C                        |                       | 0.764           |
| EFFICIENCY (T/S) SPEED (RPM)        | 11052.        |                              | POHER                 | 26.             |
| MEAN DIA (IN)                       |               | SPEED<br>S SPEE              | (RPM)                 | 11052.<br>3026. |
| EFF AREA (IN2)                      | 0.21          | HEAD                         | (FT)                  | 242.            |
| LL/C (ACTUAL)                       |               |                              | (IN)                  | 2.72            |
| MAX TIP SPEED<br>STAGES             | 260.<br>1     | TIP SI                       |                       | 132.            |
| GAMMA                               | 1.91          | VOL. F                       |                       | 282.            |
| PRESS RATIO (T/T)                   | 1.01          | FLOH (                       |                       | 0.450<br>0.200  |
| PRESS RATIO (1/S)                   |               |                              |                       |                 |
| HORSEPOWER EXIT MACH HUMBER         | 26.<br>0.02   |                              |                       |                 |
| SPECIFIC SPEED                      | 37.16         |                              |                       |                 |
| SPECIFIC DIAMETER                   | 2.13          |                              |                       |                 |
|                                     |               |                              |                       |                 |
| 4 02 TURBINE #                      |               |                              | ********              |                 |
| . 05 1000145 -                      |               |                              | 02 PUMP *             |                 |
| EFFICIENCY (T/T)                    | 0.877         |                              | ENCY                  | 0.736           |
| EFFICIENCY (T/S)                    | 0.767         | HORSEP                       |                       | 1044.           |
| SPEED (RPH)<br>HORSEPOHER           |               | SPEED                        | (RPH)                 | 83640.          |
|                                     | 1044.<br>1.49 | SS SPE                       | ED                    | 27451.          |
| MEAN DIA (IN)<br>EFF AREA (IN2)     | 0.31          | S SPEE<br>HEAD               |                       | 1458.<br>9445.  |
| U/C (ACTUAL)                        |               |                              | (IN)                  | 2.22            |
| MAX TIP SPEED                       | 617.          | TIP SP                       | EED                   | 812.            |
| STAGES<br>GAMMA                     | 1             | VOL. FI                      |                       | 279.            |
| PRESS RATIO (T/T)                   | 1.91<br>2.21  | HEAD CI<br>FLOH CI           |                       | 0.461           |
| PRESS RATIO (T/S)                   | 2.55          |                              | DEF<br>ER RATIO       | 0.137<br>0.670  |
| EXIT MACH NUMBER                    | 0.36          |                              | G DN                  |                 |
| SPECIFIC SPEED                      | 81.81         | SHAFT I                      | DIAMETER              | 18.00           |
| SPECIFIC DIAMETER                   | 1.03          |                              |                       |                 |

TABLE 42. — DUAL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER GROOVED CHAMBER)

|   | ENGINE PE                 |                                  | PARAMETERS     |                    |                  |
|---|---------------------------|----------------------------------|----------------|--------------------|------------------|
| ##  | *******                   |                                  |                |                    |                  |
| CHAM  | BER PRESSUR               | Ε                                |                | 1049.9             |                  |
|   | ENGINE THRU               |                                  |                | 37500.<br>78.15    |                  |
|   | L ENGINE FL<br>VAC. ISP   | OM RAIL                          |                | 479.8              |                  |
|   | AT AREA                   |                                  |                | 17.41              |                  |
|   | LE AREA RAT               |                                  |                | 1000.0<br>148.89   |                  |
|   | LE EXIT DIA<br>NE MIXTURE |                                  |                | 6.00               |                  |
| ETA   |                           |                                  |                | 0.993              |                  |
|   | BER COOLANT               |                                  |                | 263.<br>294.       |                  |
|   | BER COOLANT<br>LE COOLANT |                                  |                | 233.               |                  |
| NOZZ  | LE COOLANT                | DT                               |                | 315.               |                  |
| CHAM  | BER Q (HYDR               | OGEN COOL                        | ED)            | 12600.<br>8113.    |                  |
| MOZZ  | LE Q (OXYGE               | N COULED!                        |                | 0                  |                  |
|   | ENG1NE                    | STATION C                        | ONDITIONS      |                    |                  |
|   | ******                    |                                  | ********       |                    |                  |
|   | # FUEL S                  | SYSTEM CON                       | DITIONS #      |                    | BELD TH          |
| STATION   | PRESS                     | TEMP                             | FLOH<br>11.19  | ENTHALPY<br>-107.5 | 4.37             |
| B.P. INLET<br>B.P. EXIT   | 18.6<br>100.4             | 37.4<br>38.5                     | 11.19          | -103.0             | 4.39             |
| B.P. EXIT   | 100.4                     | 38.5                             | 11.19          | -103.0             | 4.39             |
| IST STAGE EXIT  | 1134.6                    | 49.9                             | 11.19          | -46.7<br>9.8       | 4.51<br>4.61     |
| PUMP EXIT<br>COOLANT INLET  | 2192.1<br>2170.2          | 61.1<br>61.3                     |                | 9.8                | 4.59             |
| COOLANT EXIT  | 1907.1                    | 355.7                            | 11.19          | 1135.6             | 0.92             |
| TBV INLET   | 1907.1<br>1888.1          | 61.3<br>355.7<br>355.7<br>356.9  | 0.56           | 1135.6<br>1135.6   | 0.91             |
| TBV EXIT<br>H2 TRB INLET<br>H2 TRB EXIT                                       | 1169.7<br>1888.1          | 356.9<br>355.7                   | 0.56<br>10.63  | 1135.6             | 0.91             |
| H2 TRB EXIT   | 1257.3                    | 327.1                            | 10.63          | 1016.9             | 0.68             |
| H2 TRB DIFFUSER   | 1216.1                    | 327.1                            | 10.63          | 1016.9<br>1016.9   | 0.66<br>0.66     |
| H2 TRB EXIT H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT                      | 1204.0                    | 327.1<br>327.1<br>327.1<br>325.9 | 10.63<br>10.63 | 1012.1             | 0.64             |
| H2 BST TRB DIFF   | 1169.7                    | 325.9                            | 10.63          | 1012.1             | 0.63             |
| HZ TANK PRESS   | 18.6                      | 327.4                            | 0.0274         | 1018.3             | 0.0107<br>0.43   |
| FSOV INLET<br>FSOV EXIT   | 1169.7                    | 327.5<br>327.5                   | 11.16<br>11.16 | 1018.3             | 0.62             |
| H2 BST TRB OUT H2 BST TRB DIFF H2 TANK PRESS FSOV INLET FSOV EXIT CHAMBER INJ | 1117.2                    |                                  |                | 1018.3             | 0.61             |
| CHAMBER   | 1049.9                    |                                  |                |                    |                  |
|   | • OXYG                    | EN SYSTEM                        | CONDITIONS     | ; <b>=</b>         |                  |
| STATION   | PRESS                     | TEMP                             | FLOH           | ENTHALPY<br>61.1   | DENSITY<br>71.17 |
| B.P. INLET<br>B.P. EXIT   | 16.0<br>135.6             | 162.7<br>163.2                   | 67.1<br>67.1   | 61.5               | 71.20            |
| PUMP INLET  | 135.6                     | 163.2                            | 67.1<br>67.1   | 61.5               | 71.20            |
| PUMP EXIT   | 4716.1                    | 184.0                            | 67.1<br>67.1   | 77.1<br>77.1       | 72.09<br>72.02   |
| COOLANT INLET   | 4668.9<br>4436.3          | 184.2<br>499.1                   | 67.1           | 198.0              | 27.64            |
| OTBY INLET  | 4436.3                    | 499.1                            | 3.0            | 198.0              | 27.64            |
| OTBV EXIT   | 1772.4                    | 450.8                            | 3.0<br>57.4    | 198.0<br>198.0     | 13.58<br>27.64   |
| 02 TRB INLET<br>02 TRB EXIT   | 4436.3<br>1976.3          | 499.1<br>404.5                   | 57.4           | 179.6              | 18.94            |
| OZ TRR DIFFUSER   | 1772.4                    | 397.6                            | 57.4           | 179.6              | 17.35            |
| 02 BST TRB IN<br>02 BST TRB OUT   | 4436.3                    | 499.1                            | 6.7<br>6.7     | 198.0<br>193.9     | 27.64<br>28.43   |
| 02 BST TRB OUT<br>02 BST TRB DIFF   | 4375.3                    | 486.7                            | 6.7            | 193.9              | 28.43            |
| OBTY INLET  | 4391.6                    | 486.7                            | 6.7            | 193.9              | 28.43            |
| OBTV EXIT   | 1772.4                    | 438.1                            | 6.7<br>67.0    | 193.9<br>181.9     | 14.24<br>16.79   |
| MIXER 02 TANK PRESS   | 1772.4<br>16.0            | 403.6<br>295.6                   | 0.153          | 181.9              | 0.16             |
| OCV INLET   | 1483.8                    | 400.4                            | 67.0           | 181.9              | 16.08            |
| OCY EXIT  | 1178.7                    | 378.7                            | 67.0<br>67.0   | 181.9<br>181.9     | 11.72<br>11.51   |
| CHAMBER INJ<br>CHAMBER  | 1155.2<br>1049.9          | 377.5                            | •7.0           | 101.7              | ••••             |
| CHARDER   | _                         |                                  |                |                    |                  |
|   | •                         | WALVE DA                         | LIA .          |                    |                  |
| VALVE   | DELTA P                   |                                  | FLOH           | * BYPASS           |                  |
| OTBV  | 2664.<br>718.             | 0.02<br>0.04                     | 3.02<br>0.56   | 5.00<br>5.00       |                  |
| TBV<br>FSOV   | 718.                      | 3.82                             | 11.16          | 2                  |                  |
| 08TV  | 2619.                     | 0.05                             | 6.71           |                    |                  |
| OCV   | 505.                      | 1.11                             | 66.99          |                    |                  |
|   | •                         | INJECTOR                         | DATA *         |                    |                  |
| #0700   | DELTA P                   | AREA                             | FLOH           | VELOCITY           |                  |
| INJECTOR  | DEL 14 P                  |                                  | 11.16          |                    |                  |

**FUEL** 

LOX

2.88

11.16

66.99

291.12

TABLE 42. — DUAL-EXPANDER ENGINE — 37,500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|                      |          |                 | ***********        |  |                 |         |
|----------------------|----------|-----------------|--------------------|--|-----------------|---------|
|                      |          |                 | HINERY PERFORMANCE |  |                 |         |
|                      |          | *******         | *************      | =                                      |                 |         |
|                      |          | RBINE .         |                    | H2 BOOST F                             |                 |         |
|                      |          | *****           |                    | * 14 8003/ 1                           |                 |         |
| EFFICIENCY           |          |                 |                    | ICIENCY                                | 0.766           |         |
| <b>EFFICIENCY</b>    | (T/S)    | 0.454           |                    | SEPONER                                | 71.             |         |
| SPEED                | (RPH)    | 33653.          |                    | ED (RPM)                               | 33653.          |         |
| MEAN DIA             | (IN)     | 1.76            | 2 2                | PEED                                   | 3049.           |         |
| EFF AREA             | (IN2)    | 4.21            | HEAL               | D (FT)                                 | 2688.           |         |
| U/C (A               | ACTUAL ) | 0.531           | DIA                | (IN)                                   | 2.98            |         |
| MAX TIP SPE          | ED       | 372.            | TIP                | SPEED                                  | 438.            |         |
| STAGES               |          | 1               | VOL.               | . FLOH                                 | 1144.           |         |
| GAMMA                |          | 1.40            | HEAL               | D COEF                                 | 0.450           |         |
| PRESS RATIO          |          |                 | FLO                | I COEF                                 | 0.201           |         |
| PRESS RATIO          | (T/S)    |                 |                    |  |                 |         |
| HORSEPOHER           |          | 71.             |                    |  |                 |         |
| EXIT MACH N          |          | 0.13            |                    |  |                 |         |
| SPECIFIC SP          |          | 150.00          |                    |  |                 |         |
| SPECIFIC DI          | AMETER   | 0.52            |                    |  |                 |         |
|                      |          | _               |                    |  |                 |         |
|                      |          |                 |                    | ###################################### |                 |         |
| * H2 TU              |          |                 |                    | * H2 PUMP                              |                 |         |
|                      |          | -               |                    | STAGE ONE                              |                 | ACE THE |
|                      |          |                 |                    | STAGE UNE                              |                 | AGE THO |
| EFFICIENCY           | (1/1)    | 0.883           | EFFICIENCY         | 0.760                                  |                 | 0.759   |
| EFFICIENCY           | (T/S)    |                 | HORSEPOHER         | 891.                                   |                 | 895.    |
| SPEED                |          | 107143.         | SPEED (RPH)        | 107143.                                |                 | 37143.  |
| HORSEPOHER           |          | 1786.           | SS SPEED           | 11935.                                 | •               |         |
| MEAN DIA.            | (IN)     |                 | S SPEED            | 1451.                                  |                 | 1433.   |
|                      | (IN2)    |                 | HEAD (FT)          | 33288.                                 |                 | 3364.   |
| U/C (A               | CTUAL)   | 0.553           | DIA. (IN)          | 3.22                                   |                 | 3.22    |
| MAX TIP SPE          | ED       | 1481.           | TIP SPEED          | 1506.                                  |                 | 1506.   |
| STAGES               |          | 1               | VOL. FLOW          | 1114.                                  |                 | 1090.   |
| GAMMA                |          | 1.40            | HEAD COEF          | 0.472                                  |                 | 0.473   |
| PRESS RATIO          | (T/T)    | 1.50            | FLOH COEF          | 0.136                                  |                 |         |
| PRESS RATIO          | (T/S)    | 1.57            | DIAMETER RATIO     | 0.472                                  |                 |         |
| EXIT MACH N          |          | 0.24            | BEARING DN         |  |                 |         |
| SPECIFIC SPE         |          | 66.16           | SHAFT DIAMETER     | 28.00                                  |                 |         |
| SPECIFIC DI          | AMETER   | 1.26            |                    |  |                 |         |
|                      |          |                 |                    |  |                 |         |
|                      |          |                 |                    | *********                              |                 |         |
| * 02 BO              |          |                 |                    | 02 BOOST P                             |                 |         |
| EFFICIENCY           | (T/T)    | 0.851           |                    | CIENCY                                 |                 |         |
| EFFICIENCY           |          |                 |                    | EPOHER                                 | 0.764<br>39.    |         |
| SPEED                | (RPH)    |                 |                    | D (RPM)                                | 9022.           |         |
| MEAN DIA             | (IN)     | 6.34            | S SP               |  | 3026.           |         |
| EFF AREA             | (11/2)   |                 | HEAD               |  | 242.            |         |
|                      | CTUAL)   |                 | DIA.               |  | 3.34            |         |
| MAX TIP SPEE         |          | 260.            |                    | SPEED                                  | 132.            |         |
| STAGES               |          | 1               |                    | FLOH                                   | 423.            |         |
| GAMMA                |          | 1.97            | HEAD               | COEF                                   | 0.450           |         |
| PRESS RATIO          | (T/T)    |                 |                    | COEF                                   | 0.200           |         |
| PRESS RATIO          | (T/S)    | 1.01            |                    |  |                 |         |
| HORSEPOHER           |          | 39.             |                    |  |                 |         |
| EXIT MACH NO         |          | 0.02            |                    |  |                 |         |
| SPECIFIC SPE         |          | 36.68           |                    |  |                 |         |
| SPECIFIC DIA         | AMETER   | 2.16            |                    |  |                 |         |
|                      |          |                 |                    |  |                 |         |
| *******              |          |                 |                    | ********                               |                 |         |
| ■ 02 TUF             |          |                 |                    | # 02 PUMP 1                            |                 |         |
| ******               |          |                 |                    |  |                 |         |
| EFFICIENCY           | (1/1)    | 0.887           |                    | CIENCY                                 | 0.750           |         |
| EFFICIENCY           |          |                 | HOKZ               | EPOHER                                 | 1488.           |         |
| SPEED<br>Horsepower  |          | 67087.<br>1488. |                    | D (RPM)                                | 67087.          |         |
| MEAN DIA             | CTAIN    |                 |                    | PEED                                   | 26973.<br>1467. |         |
| MEAN DIA<br>EFF AREA | CIN21    | 0.46            | \$ SPE             |  |                 |         |
| U/C (AC              |          |                 | HEAD<br>DIA.       |  | 9146.           |         |
| MAX TIP SPEE         |          | 602.            |                    | SPEED                                  | 2.72<br>796.    |         |
| STAGES               |          | 1               |                    | FLON                                   | 418.            |         |
| GAMMA                |          | 1.97            |                    | COEF                                   | 0.465           |         |
| PRESS RATIO          | (T/T)    |                 |                    | COEF                                   | 0.465           |         |
| PRESS RATIO          |          |                 |                    | ETER RATIO                             | 0.672           |         |
| EXIT MACH NU         |          | 0.36            |                    | ING DN                                 |                 |         |
| SPECIFIC SPE         |          | 82.37           |                    | DIAMETER                               |                 |         |
| SPECIFIC DIA         |          |                 |                    |  |                 |         |
|                      |          |                 |                    |  |                 |         |

## TABLE 43. — DUAL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER)

## ENGINE PERFORMANCE PÄRAMETERS

| CHAMBER PRESSURE            | 1022.1 |
|-----------------------------|--------|
| VAC ENGINE THRUST           | 50000. |
| TOTAL ENGINE FLON RATE      | 104.20 |
| DEL. VAC. ISP               | 479.8  |
| THROAT AREA                 | 23.84  |
| NOZZLE AREA RATIO           | 1000.0 |
| NOZZLE EXIT DIAMETER        | 174.23 |
| ENGINE MIXTURE RATIO        | 6.00   |
| ETA C*                      | 0.993  |
| CHAMBER COOLANT DP          | 226.   |
| CHAMBER COOLANT DT          | 278.   |
| NOZZLE COOLANT DP           | 235.   |
| NOZZLE COOLANT DT           | 295.   |
| CHAMBER Q (HYDROGEN COOLED) | 15803. |
| NOZZLE Q (OXYGEN COOLED)    | 10262. |

### ENGINE STATION CONDITIONS

|   |                      |                | **********  | H # 6   |                       |
|---|----------------------|----------------|---|---|-----------------------|
|   |                      |                |   |   |                       |
|   |                      |                | * SMOITIONS                                       | CATUAL DV   | DENSTITY              |
| STATION B.P. INLET B.P. EXIT PUMP INLET 1ST STAGE EXIT PUMP EXIT COOLANT INLET COOLANT INLET TBV INLET TBV EXIT H2 TRB INLET H2 TRB EXIT H2 TRB DIFFUSER H2 BST TRB OUT H2 BST TRB OUT H2 TANK PRESS FSOV INLET FSOV EXIT CHAMBER | PRESS                | 77.4           | 16.92   | ENTHALPY<br>-107.5  | 4.37                  |
| B.P. INLE!  | 10.9                 | 37.4<br>te 6   | 14.92   | -103.0  | 4.29                  |
| DIMD THEFT  | 100.8                | 38.5           | 14.92   | -103.0  | 4.29                  |
| IST STAGE EXIT  | 1081.6               | 49.0           | 14.92   | -50.4   | 4.52                  |
| PUMP EXIT   | 2088.7               | 59.3           | 14.92   | 2.5   | 4.62                  |
| COOLANT INLET   | 2067.8               | 59.5           | 14.92   | 2.5   | 4.60                  |
| COOLANT EXIT  | 1842.0               | 337.4          | 14.92   | 1061.3  | 0.93                  |
| TBV INLET   | 1823.6               | 337.5          | 0.75  | 1061.3  | 0.93                  |
| TBV EXIT  | 1138.6               | 338.3          | 0.75  | 1061.3  | 0.40                  |
| H2 TRB INLET  | 1823.6               | 337.5          | 14.18   | 1061.3  | 0.93<br>0.78          |
| H2 TRB EXIT   | 1230.1               | 310.7          | 14.18   | 75U.3   | 0.47                  |
| H2 TRB DIFFUSER   | 1184.7               | 310.7          | 14.18   | 950.3   | 0.47                  |
| H2 BST TRB IN   | 1172.9               | 310.7          | 14.18   | 945 5   | 0.44                  |
| HZ BS1 IRB UUI  | 1151.7               | 307.6          | 14.18   | 945.5   | 0.45                  |
| HZ BOI IND DIFF   | 1130.4               | 310.2          | 0.0386  | 951.3   | 0.0113                |
| ECON INTET  | 1138 6               | 311.0          | 14.89   | 951.3   | 0.+5                  |
| FSOV FREE   | 1110.1               | 311.0          | 14.89   | 951.3   | 0.63                  |
| CHAMBER INJ   | 1087.5               | 311.0          | 14.89   | 951.3   | 0.62                  |
| H2 BST TRB OUT H2 BST TRB DIFF H2 TANK PRESS FSOV INLET FSOV EXIT CHAMBER INJ CHAMBER   | 1022.1               |                |   |   |                       |
| •   |                      |                |   |   |                       |
|   | * OXYG               | EN SYSTEM      | CONDITIONS  | ; <b>•</b>  |                       |
| STATION   | PRESS                | TEMP           | FLON  | ENTHALPY  | DENSITY               |
| STATION B.P. INLET B.P. EXIT  | 16.0                 | 162.7          | 89.5  | 61.1  | 71.17                 |
| B.P. EXIT   | 135.6                | 163.2          | 89.5  | 61.5  | 71.20                 |
| PUMP INLET<br>PUMP EXIT   | 135.6                | 163.2          | 89.5  | 61.5  | 71.26<br>72.15        |
| PUMP EXIT   | 4632.1               | 183.1          | 87.5  | ENTHALPY<br>61.1<br>61.5<br>61.5<br>76.6<br>76.6<br>191.2 | 72.15                 |
| COOLANT INLET   | 4585.8               | 183.3          | 87.5  | 101.7   | 28.95                 |
| COOLANT INLET USEX.MET CELT OTBY INLET OTBY EXIT OZ TRB INLET OZ TRB DIFFUSER OZ BST TRB IN OZ BST TRB IN OZ BST TRB DIFF OBTY INLET OBTY EXIT MIXER OZ TANK PRESS  | 4351.1               | 4/8.5          | 67.7  | 191.2   | 28.95                 |
| OTBY INLE!  | 1725 0               | 478.3          | 4.0<br>4.0<br>76.6<br>76.6<br>76.6                | 191.2   | 14.43                 |
| OT TOP THE ET   | 4361 1               | 478.5          | 76.6  | 191.2   | 28.95                 |
| OZ TRB INCCI  | 1926.5               | 387.5          | 76.6  | 173.5   | 20.17                 |
| 02 TRB DIFFUSER   | 1725.0               | 380.4          | 76.6  | 173.5<br>191.2  | 18.48                 |
| OZ BST TRB IN   | 4351.1               | 478.5          | 9.0   | 191.2   | 28.95                 |
| O2 BST TRB OUT  | 4307.4               | 466.2          | 9.0   | 187.2   | 29.67                 |
| 02 BST TRB DIFF   | 4305.7               | 466.2          | 9.0   | 187.2   | 29.84                 |
| OBTY INLET  | 4305.7               | 466.2          | 9.0   | 187.2   | 29.86                 |
| OBTV EXIT   | 1725.0               | 416.2          | 9.0   | 187.2   | 15.21                 |
| MIXER   | 1725.0               | 385.3          | 89.3  | 175.7   | 18.€                  |
| 02 TANK PRESS<br>OCV INLET<br>OCV EXIT  | 16.0                 | 267.1          | 9.0<br>9.0<br>9.0<br>9.0<br>89.3<br>0.227<br>89.3 | 175.7<br>175.7  | 0.1 <b>6</b><br>17.53 |
| OCV INLET   | 1638.7               | 382.1          | 87.3  | 175.7   | 12.19                 |
| OCV EXIT  |                      | 359.2<br>358.0 |   | 175.7   | 12.44                 |
| CHAMBER INJ<br>CHAMBER  | 1124.3               | 336.0          | 67.3  | 1,,,,,  |                       |
| CHAMBER   | 1022.1               |                |   |   |                       |
|   |                      | VALVE DA       | ATA =   |   |                       |
|   |                      |                |   |   |                       |
| VALVE   | DELTA P              | AREA           | FLOH  | % BYPASS  |                       |
| OTBV  | 2626.                | 0.03           | 4.03  | 5.00  |                       |
| TBV   | 2626.<br>685.<br>28. | 0.06           | 0.75  | 5.00  |                       |
| FS0V  | 28.                  | 5.10           |   |   |                       |
| OBTV  | 2581.                | 0.07           | 8.95  |   |                       |
| OCA   | 492.                 | 1.45           | 89.32   |   |                       |
|   |                      | INJECTOR       | DATA *  |   |                       |
|   |                      | 405:           | E1 01   | WEL OCTTY   |                       |
| INJECTOR  | DELTA P              | AREA           | FLON  | VELOCITY<br>982.19  |                       |
| FUEL  | 77.                  | 3.51           | 14.89<br>89.32                                    | 982.19<br>275.70  |                       |
| LOX   | 114.                 | 3.75           | 67.32   | 2/3./4  |                       |

TABLE 43. — DUAL-EXPANDER ENGINE — 50,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  | MACHINERY PERFORMANCE DATA # |                       |
|--|------------------------------|-----------------------|
| ***********                                    |                              | ======                |
| # H2 BOOST TURBINE (                           | . 2 2005.                    | PUMP =                |
|  | *********                    |                       |
| EFFICIENCY (T/T) 0.85<br>EFFICIENCY (T/S) 0.46 |                              | 0.765                 |
| SPEED (RPM) 29210                              |                              | %.<br>29210.          |
| MEAN DIA (IN) 2.0                              | 2 S SPFFD                    | 3045.                 |
| EFF AREA (IN2) 5.5                             | 2 HEAD (FT)                  |                       |
| U/C (ACTUAL) 0.53                              | 7 DIA. (IN)                  | 3.45                  |
| MAX TIP SPEED 369<br>STAGES                    |                              | 439.                  |
| GAMMA 1.3                                      | 1 VOL. FLOM 6 HEAD COEF      | 1526.<br>0.458        |
| PRESS RATIO (T/T) 1.0                          |                              | 0.201                 |
| PRESS RATIO (T/S) 1.0                          |                              | *****                 |
| HORSEPOHER 96                                  |                              |                       |
| EXIT MACH NUMBER 0.1<br>SPECIFIC SPEED 150.0   |                              |                       |
| SPECIFIC SPEED 150.0<br>SPECIFIC DIAMETER 0.5  |                              |                       |
|  | •                            |                       |
|  | *=====                       |                       |
| # H2 TURBINE #                                 | # H2 PUR                     |                       |
| *********                                      |                              |                       |
|  | STAGE ON                     |                       |
| EFFICIENCY (T/T) 0.89                          |                              |                       |
| EFFICIENCY (T/S) 0.79                          | 7 HORSEPOHER 1110.           |                       |
| SPEED (RPH) 100008                             | SPEED (RPM) 100000.          | 100000.               |
| HORSEPOHER 2226                                |                              |                       |
| MEAN DIA. (IN) 2.99<br>EFF AREA (IN2) 1.00     |                              |                       |
| U/C (ACTUAL) 0.553                             |                              |                       |
| MAX TIP SPEED 1454.                            |                              |                       |
| STAGES   |                              |                       |
| GAIGA 1.36                                     |                              | 0.457                 |
| PRESS RATIO (T/T) 1.48                         |                              |                       |
| PRESS RATIO (T/S) 1.56 EXIT MACH NUMBER 0.26   |                              |                       |
| SPECIFIC SPEED 74.15                           |                              |                       |
| SPECIFIC DIAMETER 1.14                         |                              |                       |
|  |                              |                       |
| • 02 BOOST TURBINE •                           | - 00 0000                    |                       |
| - 05 PO021   DMBINE =                          | • 02 BOOST (                 |                       |
| EFFICIENCY (T/T) 0.857                         |                              | 0.764                 |
| EFFICIENCY (T/S) 0.815                         |                              | 52.                   |
| SPEED (RPM) 7812.                              |                              | 7812.                 |
| MEAN DIA (IN) 7.32<br>EFF AREA (IN2) 0.39      |                              | 3026.                 |
| EFF AREA (IN2) 0.39<br>U/C (ACTUAL) 0.553      |                              |                       |
| MAX TIP SPEED 260.                             |                              | 3. <b>8</b> 5<br>132. |
| STAGES 1                                       | VOL. FLOW                    | 564.                  |
| GAPPIA 2.01                                    | , L. D. 002.                 | 0.450                 |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01  | FLON COEF                    | 0.200                 |
| HORSEPOHER 52.                                 |                              |                       |
| EXIT MACH NUMBER 0.02                          |                              |                       |
| SPECIFIC SPEED 36.46                           |                              |                       |
| SPECIFIC DIAMETER 2.18                         |                              |                       |
| ***  | ********                     |                       |
| * 02 TURBINE #                                 | 4 OZ PUMP                    |                       |
| **********                                     | ******                       |                       |
| EFFICIENCY (T/T) 0.895                         | EFFICIENCY                   | 0.759                 |
| EFFICIENCY (T/S) 0.783                         | HORSEPOHER                   | 1923.                 |
| SPEED (RPM) 57463,<br>HORSEPOHER 1923.         | SPEED (RPM)                  | 57463.                |
|  | SS SPEED<br>S SPEED          | 26681.<br>1471.       |
| EFF AREA (IN2) 0.61                            | HEAD (FT)                    | 8971.                 |
|  | DIA. (IN)                    | 3.13                  |
| MAX TIP SPEED 592.                             | TIP SPEED                    | 785.                  |
| STAGES 1                                       | VOL. FLOH                    | 557.                  |
| GAPPA 2.01 PRESS RATIO (T/T) 2.26              | HEAD COEF                    | 0.468                 |
| PRESS RATIO (T/T) 2.26 PRESS RATIO (T/S) 2.62  | FLOW COEF DIAMETER RATIO     | 0.137                 |
| EXIT MACH NUMBER 0.36                          | BEARING DN                   |                       |
| SPECIFIC SPEED 82.68                           | SHAFT DIAMETER               |                       |
| SPECIFIC DIAMETER 1.03                         |                              |                       |
|  |                              |                       |

## TABLE 44. - FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR - 7500 LBF THRUST (COPPER GROOVED CHAMBER)

|                                   | DE   | oronales.       | DADAME TERS           |                    |                |
|-----------------------------------|--|-----------------|-----------------------|--------------------|----------------|
| # <b>#</b> #                      | ENGINE PE                                      |                 | PARAMETERS            |                    |                |
|                                   | NED DOECCIE                                    | nc .            |                       | 1906.0             |                |
|                                   | BER PRESSUR<br>ENGINE THRU                     |                 |                       | 7500.              |                |
| TOTAL                             | _ ENGINE FL                                    |                 |                       | 15.62              |                |
|                                   | VAC. ISP<br>AT AREA                            |                 |                       | 480.1<br>1.93      |                |
|                                   | AI AREA RAI<br>LE AREA RAI                     | 110             |                       | 1000.0             |                |
|                                   | LE EXIT DIA                                    |                 |                       | 49.52              |                |
| ENGI<br>ETA                       | NE MIXTURE                                     | RATIO           |                       | 6.00<br>0.993      |                |
|                                   | BER COOLAN                                     | T DP            |                       | 1302.              |                |
|                                   | BER COOLAN                                     |                 |                       | 747.<br>5996.      |                |
| NOZZ                              | LE/CHAMBER                                     | 4               |                       | 3,,,,,,            |                |
|                                   |  | STATION C       |                       |                    |                |
|                                   | ******   | ****            |                       |                    |                |
|                                   |  | SYSTEM COM      | DITIONS .             |                    | DENSITY        |
| STATION                           | PRESS  | TEMP<br>37.4    | FLOM<br>2.23          | ENTHALPY<br>-107.5 | 4.37           |
| B.P. INLET<br>B.P. EXIT           | 18.6<br>100.4                                  | 38.5            | 2.23                  | -103.0             | 4.39           |
| PUMP INLET                        | 100.4  | 38.5            | 2.25                  | -103.0             | 4.39           |
|                                   | 2168.6   | 77.3            | 2.23                  | 54.2<br>202.8      | 4.16<br>4.13   |
| 2ND STAGE EXIT<br>PUMP EXIT       | 4119.0<br>5994.5                               | 112.8<br>144.5  | 2.23                  | 344.0              | 4.17           |
| COLD REGEN IN                     | 5934.5<br>5875.2                               | 145.0           | 2.23                  | 344.0              | 4.15           |
|                                   | 5875.2   | 374.0           | 2.23                  | 1266.3<br>1266.3   | 2.19<br>2.19   |
| COOLINITY ETHER                   | 5875.2<br>4573.3                               | 374.0<br>1121.3 | 2.23                  | 3950.8             | 0.69           |
| COOLANT EXIT<br>TBV INLET         | 4573.3<br>4527.6<br>2199.7<br>4527.6<br>4186.7 | 1121.6          | 0.11                  | 3950.8             | 0.69           |
| TBV EXIT                          | 2199.7   | 1138.3          | 0.11                  | 3950.8             | 0.35           |
| 02 TRB INLET                      | 4527.6   | 1121.6          | 2.12<br>2.12          | 3950.8<br>3881.8   | 0.65           |
| 02 TRB EXIT<br>H2 TRB IMLET       | 4186.7   | 1104.4          | 2.12                  | 3881.8             | 0.65           |
| H2 TRB EXIT                       | 2316.5   | 983.0           | 2.12                  | 3411.2             | 0.42           |
| H2 TRB DIFFUSER                   | 2290.7   | 983.2           | 2.12                  | 3411.2<br>3411.2   | 0.41           |
| H2 BST TRB IN<br>H2 BST TRB OUT   | 2267.8   | 983.2<br>982.1  | 2.12<br>2.12          | 3406.4             | 0.41           |
| H2 BST TRB DIFF                   | 2244.4   | 982.2           | 2.12                  | 3406.4             | 0.41           |
| 02 BST TRB IN                     | 2222.0   | 982.3           | 2.12                  | 3406.4<br>3403.8   | 0.40           |
| 02 BST TRB OUT<br>02 BST TRB DIFF | 2214.1   | 981.6<br>981.7  | 2.12<br>2.12          | 3403.8             | 0.40           |
| H2 TANK PRESS                     | 18.6   | 1004.8          | 0.0018                | 3451.2             | 0.0035         |
| GOX HEAT EXCH IN                  | 2199.7   | 787.4           | 2.23                  | 3431.2             | 0.40<br>0.39   |
| GOX HEAT EXCH OU                  |  | 989.3<br>989.3  | 2.23                  | 3429.8<br>3429.8   | 0.39           |
| HOT REGEN IN                      | 2123.0   | 727.4           | 2.23                  | 2506.8             | 0.51           |
| HOT REGEN EX<br>FSOV INLET        | 2123.0   | 727.4           | 2.23                  | 2506.8             | 0.51<br>0.50   |
| FSOV EXIT                         | 2070.0   | 727.7<br>727.8  | 2.23<br>2.23          | 2506.8<br>2506.8   | 0.50           |
| CHAMBER INJ<br>CHAMBER            | 2049.3<br>1906.0                               | 727.5           | 2.23                  | 232212             |                |
| CHAIDEN                           |  |                 |                       |                    |                |
|                                   |  | GEN SYSTEM      | CONDITIONS            | ENTHALPY           | DENSITY        |
| STATION<br>B.P. INLET             | PRESS<br>16.0                                  | 162.7           | 13.4                  | 61.9               | 70.99          |
| B.P. EXIT                         | 135.2  | 165.3           | 13.4                  | 62.3               | 70.84          |
| PUMP INLET                        | 135.2  | 165.3           | 13.4                  | 62.3<br>73.2       | 70.84<br>71.17 |
| PUMP EXIT  02 TANK PRESS          | 3086.8   | 150.8<br>400.0  | 13.4<br>13.4<br>0.023 | 204.7              | 0.12           |
| OSOV INLET                        | 3056.0   | 181.0           | 2.0                   |                    | 71.12          |
| OSOV EXIT                         | 2139.2   | 184.6           | 2.0                   | 73.2<br>73.2       | 69.70<br>71.12 |
| OCV INLET                         | 3056.0<br>2139.2                               | 181.0<br>184.6  | 11.4<br>11.4          | 73.2               | 69.70          |
| OCV EXIT<br>CHAMBER INJ           | 2117.8   | 184.7           |                       | 73.2               | 69.66          |
| CHAMBER                           | 1906.0   |                 |                       |                    |                |
|                                   |  | # VALVE DA      | TA *                  |                    |                |
|                                   | DELTA P  | AREA            | FLON                  | % BYPASS           |                |
| VALVE<br>TBV                      | 2328.  | 0.01            | 0.11                  | 5.00               |                |
| FSOV                              | 53.  | 0.63            | 2.23                  |                    |                |
| OCV                               | 917.   | 0.07            | 13.39                 |                    |                |
|                                   | •  | INJECTOR        | DATA *                |                    |                |
| INJECTOR                          | DELTA P  | AREA            | FLOH                  |                    |                |
| FUEL                              | 143.   | 0.40            | 2.23                  |                    |                |
| LOX                               | 212.   | 0.16            | 13.39                 |                    |                |

TABLE 44. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 7500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

| **************************************                                  | ERY PERFORMANCE DATA   |   |
|---|--|---|
| *********   | *************  |   |
| **************  | *********  | ****  |
| * H2 BOOST TURBINE *  | * H2 BOOST P   | UMP =                                       |
| *************   | ********   |   |
| EFFICIENCY (T/T) 0.745  | EFF1C1ENCY<br>HORSEPOHER   | 0.766                                       |
| EFF1C1ENCY (T/S) 0.422<br>SPEED (RPH) 75301.                            | HORSEPOHER   | 14.   |
| MEAN DIA (IN) 1.44  | SPEED (RPM)  | 75301.                                      |
| EFF AREA (INC) 1.25   | \$ SPEED   | 3050.                                       |
| U/C (ACTUAL) 0.971  | HEAD (FT)<br>DIA. ([N]   | 2686.                                       |
| MAN TIP SPEED 572.  | TIP SPEED  | 1.33  |
| STAGES  | VOL. FLOM  | 438.  |
| GA1994 1.44   | HEAD COSE  | 228.<br>0.450                               |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01                           | HEAD COEF<br>FLOW COEF   | 0.201                                       |
| PRESS RATIO (T/S) 1.01  |  | 0.201                                       |
| HORSEPOHER 14.  |  |   |
| EXIT MACH HUMBER 0.07   |  |   |
| SPECIFIC SPEED 150.00   |  |   |
| SPECIFIC DIAMETER 0.78  |  |   |
| 444044444   |  |   |
| " HZ TURBINE "  | ######################################   |   |
| **********  | 41474444   |   |
|   |  | STAGE THO STAGE THREE                       |
|   | ********   |   |
| OFFICIONCY (T/T) 0.799  | EFFICIENCY 0.576<br>HORSEPOHER 497.  | 0.586 0.593<br>470, 446.<br>187500, 187500, |
| EFFICIENCY (T/S) 0.781  | HORSEPOHER 497.  | 470. 446.                                   |
|   |  | 187500. 187500.                             |
| PURSEPONER 1413.  | SS SPEED 9337. S SPEED 673. HEAD (FT) 70485. DIA. (IN) 2.53 TIP SPEED 2073. VOL. FLOM 241. |   |
| FEE AMEA (1991 A.C.   | 5 SPEED 673.   | 696. 713.                                   |
| HAT (ACTION ) 0.12  | MEAD (FT) 70485.   | 67813. 65115.                               |
| MAX TIP SPEED 1547  | UIA. (IN) 2.53   | 2.53 2.53                                   |
| STAGES  | VOL. FLON 241.   | 2075. 2075.                                 |
| GAPPIA 1.44   | HEAD COEF 0.528  | ****  |
| GAMMA 1.44 PRESS RATIO (T/T) 1.81 PRESS RATIO (T/S) 1.85                | HEAD COEF 0.528<br>FLOH COEF 0.088   | 0.508 0.488                                 |
|   | DIAMETER RATIO 0.291   |   |
| EXIT MACH MUMBER 8.13<br>SPECIFIC SPEED 49.52                           | BEARING DN 3.00E+06  |   |
| SPECIFIC SPEED 49.52  | SHAFT DIAMETER 14.00   |   |
| SPECIFIC DIMMETER 1.48  |  |   |
| ***************   | ************   |   |
| * 02 BOOST TURBINE *  | # 02 BOOST PUR   |   |
|   | **************   |   |
| EFFICIENCY (T/T) 0.750  | EFF ICIENCY  | 0.764                                       |
| EFFICIENCY (T/S) 0.478  | EFF (CIENCY<br>HORSEPONER<br>SPEED (RPH)   | 6.  |
| SPEED (RPH) 20162.  | SPEED (RPM)  | 20162.                                      |
| MEAN DIA (IN) 4.11<br>EFF AREA (INZ) 1.74                               | 2 ZPEED  | 3026.                                       |
| EFF AREA ([NZ) 1.74<br>U/C (ACTUAL) 1.007                               | HEAD (FT)<br>DIA. (IN)   | 242.  |
| MAX TIP SPEED 392.  | DIA. (IN)  | 1.50  |
| STAGES 1  | TIP SPEED<br>VOL. FLOW   | 132.  |
| GAPPIA 1.44   | HEAD COEF  | 85.<br>0.450                                |
| PRESS RATIO (T/T) 1.00  | FLON COEF  | 0.200                                       |
| PRESS RATIO (T/S) 1.01  | 7.22   | 0.200                                       |
| HORSEPONER 8.   |  |   |
| HORSEPONER 8. EXIT MACH MUMBER 0.05 SPECIFIC SPEED 84.62                |  |   |
| SPECIFIC SPEED 84.62  |  |   |
| SPECIFIC DIMMETER 1.33  |  |   |
| *********   | *********  |   |
| * 02 TURBINE *  | 4 02 PUMP H  |   |
| **********  | *******  |   |
| EFFICIENCY (T/T) 0.807<br>EFFICIENCY (T/S) 0.750<br>SPEED (RPH) 131236. | <b>EFFICIENCY</b>  | 0.703                                       |
| EFFICIENCY (T/S) 0.756  | HORSEPOHER   | 207.  |
| SPECED (NOWN) 131236.   | EFFICIENCY HORSEPOMER SPEED (RPM) SS SMEEN   | 131256.                                     |
| HORSEPONER 297. HEAN DIA (DH) 1.77 EFF ANEA (DH) 0.21                   | SS SPEED<br>S SPEED  | 4.349.71.                                   |
| EFF AREA (INC) 0.21   | 2 2NEED  | 1777.                                       |
| U/C (ACTUAL) 8.546  | HEAD (FT)<br>DIA. (IN)   | 5971.<br>1.19                               |
| MAK TIP SPEED 1891.   | TIP SPEED  | 684.  |
| STAGES 1  | VOL. FLON  | 85.   |
| GA494 1.44  | HEAD COEF  | 0.411                                       |
| PRESS RATIO (T/T) 1.08  | FLOH COEF  | 0.152                                       |
| PRESS RATIO (T/S) 1.09  | DIAMETER RATIO   | 0.679                                       |
| EXIT MACH MUMBER 0.00<br>SPECIFIC SPEED 51.70                           | BEARING DH 1.  | 57E+06                                      |
| SPECIFIC DIAMETER 1.50  | SHAFT DIAMETER   | 12.00                                       |
| 1.34  |  |   |
|   |  |   |
| RESEMERATOR DATA  |  |   |
|   |  |   |
| COLD SIDE HOT SIDE<br>DELP 59.25 45.44                                  |  |   |
| 23.44   |  |   |
|   |  |   |
| AREA 0.16 0.65<br>FLON 2.23 2.21  |  |   |
| EFFECTIVENESS 0.31  |  |   |
| NTU 0.45  |  |   |
| CRATIO 0.87   |  |   |
| CHEN. 7.87  |  |   |
| REGEN Q 2060.03   |  |   |
|   |  |   |

TABLE 45. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 15,000 LBF THRUST (COPPER GROOVED CHAMBER)

| ***  |                           |                         | PARAMETERS   |                  |               |
|--|---------------------------|-------------------------|--------------|------------------|---------------|
| CHANG  | ER PRESSU                 | r.                      |              | 1824.0           |               |
|  | ENGINE THRU               |                         |              | 15000.           |               |
| TOTAL  | ENGINE FL                 | OM RATE                 |              | 31.24            |               |
|  | VAC. ISP                  |                         |              | 480.1<br>4.02    |               |
|  | AT AREA<br>LE AREA RA'    | T 10                    |              | 1000.0           |               |
|  | E EXIT DI                 |                         |              | 71.58            |               |
|  | E MIXTURE                 |                         |              | 6.00             |               |
| ETA (  |                           |                         |              | 0.993            |               |
|  | BER COOLAN                |                         |              | 854.<br>567.     |               |
|  | BER COOLAN'<br>LE/CHAMBER |                         |              | 9408.            |               |
|  |                           |                         | CONDITIONS   |                  |               |
|  |                           |                         |              | ***              |               |
| STATION  | PRESS                     |                         | (DITIONS #   | ENTHALPY         | DENSITY       |
| B.P. IMLET   | 18.6                      | 37.4                    | 4.47         | -107.5           | 4.37          |
| D.D. EYIT  | 100.8                     | 18 S                    | 4.47         | -103.0           | 4.39          |
| PURP INLET   | 100.8                     | 38.5<br>64.6            | 4.47         | -103.0           | 4.39<br>4.38  |
| IST STAGE EXIT   |                           | 64.6<br>89.3            | 4.47<br>4.47 | 10.1<br>120.6    | 4.40          |
|  | 3548.9<br>5238.7          | 112.8                   | 4.47         | 228.5            | 4.46          |
| COLD REGEN IN<br>COLD REGEN EX<br>COOLANT INLET  | 5186.4                    | 113.2                   | 4.47         | 228.5            | 4.44          |
| COLID REGEN EX   | 5134.5                    | 302.9<br>302.9<br>870.4 | 4.47         | 957.5            | 2.35          |
| COOLANT INLET  | 5134.5                    | 302.9                   | 4.47<br>4.47 | 957.5<br>3063.1  | 2.35<br>0.82  |
|  | 4280.1<br>4237.3          | 870.4                   | 0.22         | 3063.1           | 0.82          |
| TBV INLET TBV EXIT 02 TRB INLET 02 TRB EXIT 12 TRB INLET 142 TRB EXIT 142 TRB DIFFUSER | 2105.1                    | 884.8                   | 0.22         | 3063.1           | 0.42          |
| 02 TRB INLET   | 4237.3                    | 870.7                   | 4.24         | 3063.1           | 0.82          |
| 02 TRB EXIT  | 3868.6                    | 855.2<br>855.2          | 4.24         | 2999.7           | 0.77<br>0.77  |
| H2 TRB INLET   | 3868.6                    | 855.2<br>767.5          | 4.24<br>4.24 | 2999.7<br>2650.7 | 0.51          |
| H2 TRB EXIT<br>H2 TRB DIFFUSER   | 2222.3                    | 767.7                   | 4.24         | 2650.7           | 0.50          |
| HZ REST TRR IN   | 2171.8                    |                         | 4.24         | 2650.7           | 0.50          |
| H2 BST TRB IN<br>H2 BST TRB OUT<br>H2 BST TRB DIFF                                     | 2154.6                    | 766.6                   | 4.24         | 2646.0           | 0.50          |
| H2 BST TRB DIFF  | 2147.8                    | 766.6<br>766.8          | 4.24         | 2646.0           | 0.49          |
|  | 2126.3                    | 766.B<br>766.1          | 4.24<br>4.24 | 2646.0<br>2643.4 | 0.49          |
| OR BET THE DIEE  | 2117.5                    | 766.1                   | 4.24         | 2643.4           | 0.49          |
| H2 TANK PRESS GOX HEAT EXCH IN GOX HEAT EXCH OUT                                       | 18.6                      | 784.8                   | 0.0046       | 2664.4           | 0.0045        |
| GOX HEAT EXCH IN   | 2105.l                    | 772.1                   | 4.46         | 2664.4           | 0.48          |
| GOX HEAT EXCH OUT  | 2094.6                    | 771.8                   | 4.46         | 2663.0<br>2663.0 | 0.48<br>0.48  |
| HOT REGEN IN   | 2094.6                    | 771.8<br>567.1          | 4.46<br>4.46 | 1933.3           | 0.62          |
| HOT REGEN EX   | 2031.8                    | 567.1                   | 4.46         | 1933.3           | 0.62          |
| FSOV EXIT  | 1981.0                    | 667 6                   | 4.46         | 1933.3           | 0.61          |
| FSOV INLET<br>FSOV EXIT<br>CHAMBER INJ   | 1961.2                    | 567.4                   | 4.46         | 1933.3           | 0.60          |
| CHAMBER  | 1824.0                    |                         |              |                  |               |
|  | * OXY                     | EN SYSTEM               | CONDITIONS   | ENTHALPY         | DENSITY       |
| STATION  | PRESS<br>16.0             | 162.7                   | 26.8         | 61.9             | 70.99         |
| B.P. INLET<br>B.P. EXIT  | 135.2                     | 165.3                   | 26.8         | 62.3             | 70.84         |
| CT   | 176 2                     | 145 8                   | 26.8         | 62.3             | 70.84         |
| PUMP EXIT  02 TANK PRESS   | 2954.0                    | 179.2                   | 26.8         | 72.4             | 71.31         |
| 02 TANK PRESS  | 16.0                      | 400.0                   | 0.046        | 204.7<br>72.4    | 0.12<br>71.26 |
| USUN INCE!   | 2924.5<br>2047.1          | 179.3<br>182.7          | 4.0<br>4.0   | 72.4             | 69.90         |
| OSOV EXIT  | 2924.5                    | 179.3                   |              | 72.4             | 71.26         |
| OCV EXIT   | 2047.1                    | 182.7                   | 22.8         | 72.4             | 69.90         |
| CHAMBER INJ  | 2026.7                    | 182.8                   | 26.8         | 72.4             | 69.87         |
| CHAMBER  | 1824.0                    |                         |              |                  |               |
|  |                           | ■ VALVE D               | ATA 4        |                  |               |
| VALVE  | DELTA P                   |                         | FLON         | * BYPASS         |               |
| TBV  | 2132.                     |                         | 0.22<br>4.46 | 5.00             |               |
| FSOV   | 51.<br>877.               |                         |              |                  |               |
| ocv  |                           | INJECTOR                |              |                  |               |
|  |                           |                         | FLOH         |                  |               |
| INJECTOR   | DELTA P<br>137.           |                         |              |                  |               |
| Fuel.<br>Lox   | 203.                      |                         |              |                  |               |
|  |                           |                         |              |                  |               |

TABLE 45. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR
— 15,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  | FRY PERFORMANCE DATA                        |   |  |
|--|---|---|--|
| **********   | ****************                            |   |  |
| *************  | *********                                   |   |  |
| # H2 SOOST TURBIN€ #   | 4 H2 BOOST P                                |   |  |
| EFFICIENCY (T/T) 0.796<br>EFFICIENCY (T/S) 0.519                 | EFF1C1ENCY<br>HORSEPONER                    | 0.765                                   |  |
| SPEED (RPM) 53383.   | HORSEPOMER<br>SPEED (RPM)                   | 29.                                     |  |
| MEAN DIA (IN) 1.44<br>EFF AREA (IN2) 2.11                        | S SPEED                                     | 53283.<br>3045.                         |  |
| EFF AREA (IN2) 2.11  | HEAD (FT)<br>DIA. (IN)                      | 2701.                                   |  |
| U/C (ACTUAL) 0.686<br>MAX TIP SPEED 433.                         | DIA. (IN)<br>TIP SPEED                      | 1.89<br>439.                            |  |
| STAGES 1   | VOL. FLOH                                   | 457.                                    |  |
| GAMMA 1.39<br>PRESS RATIO (T/T) 1.01                             | HEAD COEF                                   | 0.450                                   |  |
| PRESS RATIO (1/1) 1.01   | FLOM COEF                                   | 0.201                                   |  |
| HORSEPONER 29.   |   |   |  |
| EXIT MACH NUMBER 0.07<br>SPECIFIC SPEED 150.00                   |   |   |  |
| SPECIFIC DIAMETER 0.65   |   |   |  |
|  |   |   |  |
| **************************************                           |   |   |  |
| **************   | 4 H2 PUMP                                   |   |  |
|  |   | STAGE THO STAGE THE                     |  |
| EFFICIENCY (T/T) 8.807   | EFFICIENCY 0.649                            | 0.652 0.653                             |  |
| EFFICIENCY (T/T) 8.807 EFFICIENCY (T/S) 0.784 SPEEN (ROM) 156567 |   | 699. 682.                               |  |
| SPEED (RPH) 136363.  | SPEED (RPM) 156363.                         | 699. 682.<br>136363. 136363.            |  |
| HORSEPOHER 2096.<br>HEAN DIA. (IN) 2,48<br>EFF AREA (IN2) 8,23   | SS SPEED 9545.<br>S SPEED 790.              |   |  |
| EFF AREA (IN2) 8.23  | HEAD (FT) 57137.                            | 799. 806.<br>56051. 54879.<br>3.12 3.12 |  |
| U/C (ACTUAL) 0.499   | DIA. (IM) 3.12                              | 3.12 3.12                               |  |
|  | TIP SPEED 1857.<br>VOL. FLON 458.           | 1857. 1857.<br>455. 458.                |  |
| GAPPIA 1.39  | HEAD COEF 0.533<br>FLOH COEF 0.096          | 0.523 0.512                             |  |
| PRESS RATIO (T/T) 1.74   | FLON COEF 0.096                             |   |  |
| PRESS RATIO (T/S) 1.77 EXIT MACH HUMBER 0.14                     | DIAMETER RATIO 0.531                        |   |  |
| EXIT MACH NUMBER 0.14<br>SPECIFIC SPEED 43.34                    | BEARING DN 3.00E+06<br>SHAFT DIAMETER 22.00 |   |  |
| SPECIFIC DIAMETER 1.63   |   |   |  |
| ******   | *********                                   | 4+++                                    |  |
| # 02 800ST TURBINE #   | # 02 B00ST PU                               |   |  |
| FFFICIENTY (T/T) n m24   | ######################################      | 4444                                    |  |
| EFFICIENCY (T/T) 0.824<br>EFFICIENCY (T/S) 0.648                 | EFFICIENCY<br>HORSEPOHER                    | 15.                                     |  |
| SPEED (RPH) 14257.   | SPEED (RPM)                                 | 14257.                                  |  |
| MEAN DIA (IN) 4.11<br>EFF AREA (IN2) 2.97<br>U/C (ACTUAL) 0.712  | S SPEED<br>HEAD (ET)                        | 3026.<br>242.                           |  |
| U/C (ACTUAL) 0.712   | HEAD (FT)<br>DIA. (IN)                      | 2.11                                    |  |
| MAX TIP SPEED 290.<br>STAGES 1                                   | TIP SPEED                                   | 132.                                    |  |
| GAPMA (.39   | VOL. FLON<br>HEAD COEF                      | 170.<br>0.450                           |  |
| PRESS RATIO (T/T) 1.00   | HEAD COEF<br>FLOW COEF                      | 0.200                                   |  |
| PRESS RATIO (T/S) 1.01<br>HORSEPOMER 15.                         |   |   |  |
| EXIT MACH NUMBER 0.04<br>SPECIFIC SPEED 96.31                    |   |   |  |
|  |   |   |  |
| SPECIFIC DIAMETER 1.01   |   |   |  |
| **********   | ********                                    |   |  |
| * OZ TURBINE *   | 1 02 PUPP +                                 |   |  |
| EFFICIENCY (T/T) 0.822   | EFFICIENCY                                  | 0.730                                   |  |
| EFFICIENCY (T/S) 0.766   | EFF1CTENCY<br>HORSEPOWER                    | 180                                     |  |
| SPEED (RPH) 90118,<br>HORSEPOHER 380,                            | SPEED (RPM)<br>SS SPEED                     | 90118.<br>23201.                        |  |
| HORSEPOMER 380. HEAN DIA (IN) 2.48 EFF AREA (IN2) 0.36           | SS SPEED<br>S SPEED                         | 1787.                                   |  |
| EFF AREA (1N2) 0.36<br>U/C (ACTUAL) 0.548                        | HEAD (FT)                                   |   |  |
| MAX TIP SPEED 1044.  | DIA. (IN)<br>TIP SPEED                      | 1.68<br>660.                            |  |
| STAGES (   | VOL. FLOH                                   | 169.                                    |  |
| GAMMA E.39 PRESS RATIO (T/T) E.10                                | HEAD COEF                                   | 0.420                                   |  |
| PRESS RATIO (T/S) 1.10   | FLON COEF<br>DIAMETER RATIO                 | 0.153<br>0.680                          |  |
| EXIT MACH NUMBER 0.09  | BEARING DN 3                                | .44E • 06                               |  |
| SPECIFIC SPEED 49.91<br>SPECIFIC DIAMETER 1.57                   | SHAFT DIAMETER                              | 16.00                                   |  |
| Sectific Blancier 1.57   |   |   |  |
|  |   |   |  |
| REGEMERATOR DATA   |   |   |  |
| COLD SIDE HOT SID  | Ε   |   |  |
| DELP 51.87 62.8  | 4   |   |  |
| DELT 189.70 -204.6<br>AREA 0.32 L.2                              |   |   |  |
| FLOH 4,47 4,4  |   |   |  |
| EFFECTIVENESS 0.31   |   |   |  |
| NTU 0.46<br>CRATIO 0.93  |   |   |  |
| CHIH 15.92   |   |   |  |
| REGEN Q 3257.29  |   |   |  |
|  |   |   |  |

# TABLE 46. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 25,000 LBF THRUST (COPPER GROOVED CHAMBER)

| ENGINE | PERFORMANCE | PARAMETERS |     |
|--------|-------------|------------|-----|
|        |             |            | • • |

| CHAMBER PRESSURE       | 1718.0 |
|------------------------|--------|
| VAC ENGINE THRUST      | 25000. |
| TOTAL ENGINE FLOW RATE | 52.08  |
| DEL. VAC. ISP          | 480.1  |
| THROAT AREA            | 7.12   |
| NOZZLE AREA RATIO      | 1000.0 |
| NOZZLE EXIT DIAMETER   | 95.20  |
| ENGINE MIXTURE RATIO   | 6.00   |
| ETA C.                 | 0.993  |
| CHAMBER COOLANT DP     | 778.   |
| CHAMBER COOLANT DT     | 443.   |
| MOZZI E /CHAMRED O     | 12628. |

#### ENGINE STATION CONDITIONS

|  |                                      |   |                      | ***              |                |
|--|--------------------------------------|---|----------------------|------------------|----------------|
|  |                                      |   |                      |                  |                |
|  | • FUEL                               | SYSTEM CO                                 | NDITIONS *           |                  | 000 m 1 m      |
| STATION  | PRESS                                | TEMP                                      | FLOH                 | ENTHALPY         | 4.37           |
| B.P. INLET   | 18.6                                 | 37.4                                      | 7.45                 | -107.5<br>-103.0 | 4.39           |
| B.P. EXIT  | 100.6                                | 38.5                                      | 7.45                 | -103.0           | 4.39           |
| PUMP INLET<br>1ST STAGE EXIT<br>2ND STAGE EXIT   | 100.6                                | 38.5                                      | 7.45<br>7.45         | -8.8             | 4.49           |
| IST STAGE EXIT   | 1709.0                               | 58.8<br>78.3                              | 7.45                 | 85.0             | 4.57           |
| 2ND STAGE EXIT   | 4968.4                               | /8.3<br>67 T                              | 7.45                 | 177.8            | 4.66           |
|  | 4918.8                               | 97.3<br>97.7                              | 7.45                 | 177.8            | 4.63           |
| COLD REGEN IN COLD REGEN EX  | 4949 6                               | 258.6                                     | 7.45                 | 763.8            | 2.56           |
| COOR ANT IM ET   | 4869.6<br>4869.6<br>4091.5<br>4050.6 | 258.6                                     | 7.45                 | 763.8            | 2.56           |
| COOLANT INLET  | 4091.5                               | 701.7<br>702.0<br>714.7<br>702.0          | 7.45                 | 2459.0           | 0.97           |
| TRY INLET  | 4050.6                               | 702.0                                     | 0.37                 | 2459.0           | 0.96           |
| TBV INLET  | 1982.9                               | 714.7                                     | 0.37                 | 2459.0           | 0.49           |
|  |                                      | 702.0                                     | 7.08                 | 2459.0           | 0.96           |
| OZ TRB EXIT  | 3666.1                               | 688.1                                     | 7.08                 | 2401.0           | 0.90           |
| HC TRB INLET   | 3666.1                               | 688.1                                     | 7.08                 | 2401.0           | 0.90           |
| HC TRB EXIT  | 2116.3                               | 614.2                                     | 7.08                 | 2105.4           | 0.60           |
| C2 TRB INLET C2 TRB EXIT H2 TRB INLET H2 TRB EXIT H2 TRB DIFFUSER H2 BST TRB IN H2 BST TRB OUT                               | 2079.7                               | 614.4                                     | 7.08                 | 2105.4           | 0.59           |
| HZ BST TRB IN  | 2058.9                               | 614.4                                     | 7.08                 | 2105.4           | 0.59           |
| HC BST TRB OUT   | 2039.0                               | 613.3                                     | 7.08                 | 2100.6           | 0.58           |
| HZ BST TRB DIFF  | 2024.3                               | 613.4                                     | 7.08                 | 2100.6           | 0.58<br>0.57   |
| OC BST TRB IN  | 2004.1                               | 613.5                                     | 7.08                 | 2100.6           | 0.57           |
| OC BST TRB OUT   | 1994.3                               | 612.8                                     | 7.08                 | 2098.1<br>2098.1 | 0.57           |
| CC BST TRB DIFF  | 1992.9                               | 612.8                                     | 7.08                 |                  | 0.0057         |
| HC BST TRB OUT HC BST TRB DIFF CC BST TRB IN CC BST TRB OUT CC BST TRB DIFF HC TANK PRESS GOX HEAT EXCH IN GOX HEAT EXCH OUT | 18.6                                 | 628.0                                     | 7.66                 | 2116.1<br>2116.1 | 0.56           |
| GOX HEAT EXCH IN   | 1982.9                               | 617.6                                     | 7.44                 | 2114.8           | 0.56           |
| GOX HEAT EXCH UD   | 1 1773.0                             | 417.6                                     | 7.44                 | 2114.8           | 0.56           |
| HOT REGEN IN   | 1973.0                               | 457.0                                     | 7.44                 | 1528.0           | 0.72           |
| GOX HEAT EXCH OUT<br>HOT REGEN IN<br>HOT REGEN EX<br>FSOV INLET<br>FSOV EXIT<br>CHAMBER INJ                                  | 1913.8                               | 617.6<br>457.0<br>457.0<br>457.2<br>457.3 | 7.44                 |                  | 0.72           |
| FORM EVIT  | 1865.9                               | 457.2                                     | 7.44<br>7.44<br>7.44 | 1528.0           | 0.71           |
| CHAMBER INJ  | 1867.3                               | 457.3                                     | 7.44                 | 1528.0           | 0.70           |
| DHAMBER  | 1718.0                               |   |                      |                  |                |
| C. C   |                                      |   |                      |                  |                |
|  | * OXY                                | DEN SYSTEM                                | CONDITIONS           | S #              |                |
| STATION<br>B.P. INLET  | PRESS                                | TEMP                                      | FLOH                 | ENTHALPY<br>61.9 | DENSITY        |
| B.P. INLET   | 16.0                                 | 162.7                                     | 44.7                 | 61.9             | 70.99<br>70.84 |
| B.P. EXIT  | 135.2                                | 165.3                                     |                      | 62.3<br>62.3     | 70.84          |
| PUMP INLET   | 135.2                                | 165.3                                     | 44.7<br>44.7         | 71.5             | 71.37          |
| PUMP INLET PUMP EXIT 02 TANK PRESS   | 2782.4                               | 177.7                                     | 44.7                 | 204.7            | 0.12           |
| PUMP EXIT  02 TANK PRESS  050V INLET  050V EXIT  | 16.0                                 | 400.0                                     | 0.076<br>6.7         | 71.5             | 71.33          |
| OSOV INLET   | 2754.5                               | 181.1                                     | 6.7                  | 71.5             | 70.04          |
| OSOV EXII  | 2754.5                               | 177.9                                     | 87.9                 | 71.5             | 71.33          |
| OCV INLET  | 1420 2                               | 191 1                                     | 37.9<br>37.9         | 71.5             | 70.04          |
| OCV EXIT<br>CHAMBER THU  | 1908.9                               | 181.1                                     |                      | 71.5             | 70.01          |
| CHAMBER  | 1718.0                               |   |                      |                  |                |
| CINCER   | ••••                                 |   |                      |                  |                |
|  |                                      | WALVE D                                   |                      |                  |                |
| VALVE  | DELTA P                              | AREA                                      | FLOH                 | % BYPASS<br>5.00 |                |
| TBV  | 2068.                                | 0.02                                      | 0.37                 | 5.00             |                |
| FSOV   | 48.                                  | 1.04                                      | ,                    |                  |                |
| ocv  | 826.                                 | 0.23                                      | 44.64                |                  |                |
|  |                                      | INJECTOR                                  | DATA *               |                  |                |
| INJECTOR   | DELTA P                              | AREA                                      | FLOW                 |                  |                |
| FUEL   | 129.                                 | 1.17                                      | 7.44                 |                  |                |
| LOX  | 191.                                 | 0.58                                      | 44.64                |                  |                |
|  |                                      |   |                      |                  |                |

TABLE 46. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 25,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|  | MERY PERFORMANCE DATA     |  |
|--|---------------------------|--|
|  | *****************         |  |
| ***************  |                           |  |
| • H2 BOOST TURBINE •   |                           | DOST PUMP +  |
| EFFICIENCY (T/T) 0.814   | EFFICIENCY                | 0.766  |
| EFFICIENCY (T/S) 0.407   | EFFICIENCY<br>HORSEPONEF  | . 48.  |
| SPEED (RPH1 41283.   | SPEED (F                  | PM1 41283.   |
| MEAN DIA (IN) 1.44<br>EFF AREA (IN2) 3.01  | 2 SPEED                   | 3048.<br>FT) 2693.   |
| U/C (ACTUAL) 0.531   | HEAD I                    | (H) 2.43   |
| MAX TIP SPEED 380.   | TIP SPEEN                 | 410  |
| STACES I   | VOL. FLOM                 | 762.   |
| GAMMA 1.43 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.02 MODERDINER  | HEAD COEF<br>FLOH COEF    | 0.450  |
| PRESS RATIO (T/S) 1.02   | FEOM COEF                 | 0.201  |
| non ser unen 4g.   |                           |  |
| EXIT MACH NUMBER 0.11 SPECIFIC SPEED 149.74  |                           |  |
| SPECIFIC SPEED 149.74<br>SPECIFIC DIAMETER 0.51  |                           |  |
| Sectific Binetics 0.51   |                           |  |
| *******  |                           | ******   |
| # H2 TURBINE *   |                           | PUP :  |
| ***********  |                           | E ONE STAGE THO STAGE THREE                                |
|  | ****                      |  |
| EFFICIENCY (T/T) 0.861   | EFFICIENCY 0              | .708 0.707 8.706<br>994. 987. 979.<br>008. 125000. 125000. |
| EFFICIENCY (T/S) 0.828   | HORSEPONER                | 994. 987. 979.   |
| SPEED (RPH) 125000.<br>HORSEPOMER 2959.  | SS SPEED 125              | 347.   |
| MEAN DIA. (IN) 2.60  | S SPEED                   | 992. 988. 987.   |
| SPEEU (RPH) (25000. HORSEPOMER 2959. MEAN DIA. (IN) 2.60 EFF AREA (IN2) 0.36 U/C (ACTUAL) 0.521 MAX TIP SPEED 1514 | HEAD (FT) 51              | 958. 51522. S1037.   |
| U/C (ACTUAL) 0.521<br>MAX TIP SPEED 1539.  | DIA. (IN) TIP SPEED 1     | 3.29 3.29 3.29<br>794. 1794. 1794.                         |
| STAGES 2   | VOI FLOW                  | 746 781 718  |
| 0.72   | HEAD COSF 0               | .519 0.515 0.510   |
| PRESS RATIO (T/T) 1.73   | FLON CORDF 0              | .110   |
| PRESS RATIO (T/S) 1.77   | DIAMETER RATIO 0          | . 383<br>F+04  |
| PRESS RATIO (T/S) 1.77 EXIT MACH HUMBER 0.17 SPECIFIC SPEED 55.08  | SHAFT DIAMETER 2          | 4.00   |
| SPECIFIC DIAMETER 1.39   |                           |  |
| **************   | ******                    | *******  |
| # 02 BOOST TURBINE #   |                           | OST PUMP .   |
| 444144444444444444   | ******                    |  |
| EFFICIENCY (T/T) 0.876   | EFFICIENCY                | 0.764<br>26.<br>PM) 11043.                                 |
| EFFICIENCY (T/S) 0.730<br>SPEED (RPH) 11043.   | HORSEPOHER                | Z6.<br>PM1 1102 t  |
| MEAN DIA (IN) 4.11   | < < CPFFT1                | 3026.  |
| MEAN DIA (IN) 4.11<br>EFF AREA (IN2) 4.34  | HEAD (                    | FT) 242.<br>IN) 2.73                                       |
| U/C (ACTUAL) 0.552   | DIA. (                    | IN) 2.73   |
| MAX TIP SPEED 234.<br>STAGES I   | TIP SPEED<br>VOL. FLOW    |  |
| CAMMA I 4 T  | HEAD COEF<br>FLOM COEF    | 0.450  |
| PRESS RATIO (T/T)   1.00<br>PRESS RATIO (T/S)   1.01   | FLOM COEF                 | 0.200  |
|  |                           |  |
| HORSEPOMER 26.<br>EXIT MACH NUMBER 0.04  |                           |  |
| EXIT MACH NUMBER 0.04<br>SPECIFIC SPEED 99.07  |                           |  |
| SPECIFIC DIAMETER 0.86   |                           |  |
| **********   | *****                     | *****  |
| # Q2 TURBINE *   | ■ 02                      | PUMP .   |
|  |                           |  |
| EFFICIENCY (T/T) 0.854<br>EFFICIENCY (T/S) 0.791   | EFFICIENCY<br>HODGEROLLED | 0.747<br>581.  |
| SPEED (RPM) 67533.   | SPEED (R                  | PM) 67533.   |
| HORSEPONER 581. HEAN DIA (IN) 2.60 EFF AREA (IN2) 0.55   | SS SPEED<br>S SPEED       | 22446.   |
| MEAN DIA (IN) 2.60   | S SPEED                   | (813.<br>FT) 5339.   |
| U/C (ACTUAL) 0.450   | HEAD (                    | FT1 5339.<br>IN1 2.15                                      |
| MAX TIP SPEED 834.   | TIP SPEED                 | 635.   |
| STAGES 1   | VOL. FLON                 | 281.   |
| GAMMA 1.45<br>PRESS RATIO (T/T) 1.10   | HEAD COEF<br>FLON COEF    | 0.426<br>0.154   |
| PRESS RATIO (1/1) 1.10 PRESS RATIO (1/5) 1.11  | DIAMETER R                |  |
| EXIT MACH NUMBER 0.10  | BEARING DN                | 1.49E+06   |
| SPECIFIC SPEED 48.64   | SHAFT DIAM                | ETER 22.00   |
| SPECIFIC DIAMETER 1.37   |                           |  |
|  |                           |  |
| REGENERATOR D  |                           |  |
| COLD SIDE HOT  |                           |  |
|  | 1.19                      |  |
| DELT 160.89 -16  | 0.52                      |  |
|  | 1.90                      |  |
| FLOH 7.45<br>EFFECTIVENESS 0.31  | 7.44                      |  |
| NTU 0.47   |                           |  |
| CRATIO 1.00  |                           |  |
| CHIN 27.13   |                           |  |
| REGEN 0 4365.10  |                           |  |

#### TABLE 47. - FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR - 37,500 LBF THRUST (COPPER GROOVED CHAMBER)

INJECTOR

LOX

| **   |  |                         | E PARAMETER                       |                                  |                |
|--|--|-------------------------|-----------------------------------|----------------------------------|----------------|
| ~  | DED DDECC!   | oc                      |                                   | 1612.0                           |                |
|  | BER PRESSU<br>ENGINE THR   |                         |                                   | 37500.                           |                |
|  | L ENGINE F   | LOH RATE                |                                   | 78.12                            |                |
|  | VAC. ISP<br>AT AREA  |                         |                                   | 480.0<br>11.37                   |                |
|  | LE AREA RA   | 110                     |                                   | 1000.0                           |                |
|  | LE EXIT DI   |                         |                                   | 120.34<br>6.00                   |                |
| ENGI<br>ETA  | NE HIXTURE<br>CH   | RATIO                   |                                   | 0.993                            |                |
|  | BER COOLAN   | IT DP                   |                                   | 694.                             |                |
|  | BER COOLAN   |                         |                                   | 375.<br>16426.                   |                |
| NO22   | LE/CHAMBER<br>ENGINE   |                         | CONDITIONS                        | 10420.                           |                |
|  |  |                         | **********                        | ***                              |                |
| STATION  | PRESS  | TEMP                    | NDITIONS #                        | ENTHALPY                         | DENSITY        |
| B.P. INLET   | 18.6   | 37.4                    | 11.18                             | -107.5                           | 4.37           |
| B.P. EXIT  | 100.9  | 38.5<br>38.5<br>57.2    | 11.18                             | -103.0<br>-103.0                 | 4.39<br>4.39   |
| PUMP INLET  1ST STAGE EXIT   | 1675.9   | 57.2                    | 11.18                             | -13.9                            | 4.52           |
| 2ND STAGE EXIT   | 3279.3   | 75.2                    | 11.18                             | 75.0                             | 4.63           |
| PUMP EXIT  | 4908.3   | 92.7                    | 11.18<br>11.18                    | 163.7<br>163.7                   | 4.72<br>4.70   |
| COLD REGEN IN<br>COLD REGEN EX<br>COOLANT INLET  | 3279.3<br>4908.3<br>4859.2<br>4810.6<br>4810.6<br>4116.6<br>4075.4 | 226.8                   | 11.18                             | 629.7                            | 2.81           |
| COOLANT INLET  | 4810-4   | 226.8                   | 11.18                             | 629.7                            | 2.81           |
| COOLANT EXIT   | 4116.6<br>4075.4   | 601.4<br>601.7          | 0.56                              | 2099.3<br>2099.3                 | 1.11           |
| TBV INLET TBV EXIT 02 TRB INLET 02 TRB EXIT 12 TRB INLET 142 TRB EXIT 142 TRB DIFFUSER | 1860.5   | 613.9                   | 0.56                              | 2099.3                           | 0.53           |
| 02 TRB INLET   | 4075.4   | 601.7<br>589.5<br>589.5 | 10.62                             | 2099.3                           | 1.10           |
| 02 TRB EXIT  | 3662.2   | 589.5<br>589.5          | 10.62<br>10.62                    | 2046.1<br>2046.1                 | 1.02           |
| H2 TRB EXIT  | 2006.9   | 521.2                   | 10.62                             | 1765.3                           | 0.67           |
| HZ TRB DIFFUSER  | 1966.7   | 521.4                   | 10.62                             | 1765.3<br>1765.3                 | 0.65<br>0.65   |
| H2 BST TRB IN H2 BST TRB BUT H2 BST TRB BIFF C2 BST TRB IN                             | 1947.0   | 521.4                   | 10.62<br>10.62<br>10.62<br>10.62  | 1760.5                           | 0.64           |
| HZ BST TRB BIFF  | 1901.6   | 520.4                   | 10.62                             | 1760.5                           | 0.64           |
| 02 BST TRB IN<br>02 BST TRB OUT  | 1882.6<br>1871.8   | 520.4<br>519.8          | 10.62<br>10.62                    | 1760.5<br>1758.0                 | 0.63           |
|  |  | 519.8                   | 10.62                             | 1758.0                           | 0.63           |
| HE TANK PRESS  | 18.6   | 532.0                   | 0.0169<br>11.16<br>11.16<br>11.16 | 1775.0                           | 0.0066         |
| GOX HEAT ENCH IN   | 1860.5   | 524.5<br>524.2          | 11.16                             | 1775.0<br>1773.7                 | 0.62<br>0.62   |
| HOT REGEN IN   | 1851.2   | 524.2                   | 11.16                             | 1773.7                           | 0.62           |
| HOT REGEN EX<br>FSOV INLET<br>FSOV EXIT<br>CHANGER INJ                                 | 1795.7   | 399.3                   | 11.16                             | 1307.0                           | 0.78           |
| FSOV INLET   | 1795.7<br>1750 B   | 399.3<br>399.4          | 11.16<br>11.16                    | 1307.0<br>1307.0                 | 0.78<br>0.76   |
| CHAMBER INJ  | 1733.3   | 399.5                   | 11.16                             | 1307.0                           | 0.75           |
| CHWIGHER   |  |                         |                                   | _                                |                |
| STATION  | # OXY  | GEN SYSTEM              | CONDITIONS<br>FLOH                | ENTHALPY                         | DENSITY        |
| B.P. INLET   | 16.0   | 162.7                   | 67.1                              | 61.9                             | 70 99          |
| B.P. EXIT  | 135.2  | 165.3                   | 67.1                              | ENTHALPY<br>61.9<br>62.3<br>62.3 | 70.84<br>70.84 |
| PUMP INLET PUMP EXIT   | 135.2<br>2610.7  | 165.3<br>176.6          | 67.l<br>67.1                      | 62.3<br>70.8                     | 71.40          |
| OC TANK PRESS  | 16.0   | 400.0                   | 0.114                             | 204.7                            | 0.12           |
| OSOV INLET   | 2584.6   | 176.7                   | 10.0                              | 70.8<br>70.8                     | 71.36<br>70.14 |
| OSOV EXIT  | 1809.2<br>2584.6   | 179.6<br>176.7          | 10.0<br>56.9                      | 70.8                             | 71.36          |
| OCY EXIT   | 1809.2   | 179.6                   | 56.9                              | 70.8                             | 70.14          |
| CHWHBER INJ  | 1791.1   | 179.7                   | 67.0                              | 70.8                             | 70.12          |
| CHAMBER  | 1612.0   | ■ VALVE DA              | ATA .                             |                                  |                |
|  |  |                         |                                   |                                  |                |
| VALVE  | DELTA P  | AREA                    | FLOH<br>0.54                      | % BYPASS<br>5 00                 |                |
| TBV<br>FSOV  | 2215.<br>45.   | 0.02<br>2.75            | 0.56<br>11.16                     | 5.00                             |                |
| OCV  | 775.   | 0.36                    | 66.96                             |                                  |                |
|  |  |                         |                                   |                                  |                |

. INJECTOR DATA .

FLOW 11.16 66.96

AREA

1.75 0.89

DELTA P

121. 179.

TABLE 47. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 37,500 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

| 4+4+4++++++  | ***********   |                               |
|--|---|-------------------------------|
| <ul> <li>TURBOHACHI</li> </ul>   | ERY PERFORMANCE DATA .  |                               |
|  | *****************   |                               |
| * H2 8005T TURBINE *   | 442 80057 0   |                               |
| *****************  | • H2 BOOST P  |                               |
| EFFICIENCY (T/T) 0.795   | EFFICIENCY<br>HORSEPOHER  | 0.765                         |
| EFFICIENCY (T/S) 0.358   | HORSEPOHER  | 72.<br>33756.                 |
| SPEED (RPM) 33756.<br>MEAN DIA (IM) 1.44   | SPEED (RPM)<br>S SPEED  | 33756.                        |
| MEAN DIA (IN) 1.44<br>EFF AREA (IM2) 4.01<br>U/C (ACTUAL) 0.434  | S SPEED (FT)  | 3045.<br>2702.                |
| U/C (ACTUAL) 0.434   | HEAD (FT)<br>DIA. ([N]  | 2.98                          |
| MAN TIP SPEED \$24.  | TIP SPEED   | 440.                          |
|  | VOL. FLOM   | 1143.                         |
| PRESS PATIO (T/T) 1 MI   | HEAD COEF<br>FLOH COEF  | 0.450                         |
| PRESS RATIO (T/S) 1.03   | read cater  | 0.201                         |
| GAMMA 1.36 PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.03 HORSEPOMER 72.  |   |                               |
| HORSEPOHER 72. EXIT MACH NUMBER 0.14 SPECIFIC SPEED 123.78   |   |                               |
| SPECIFIC SPEED 123.78 SPECIFIC DIAMETER 0.48   |   |                               |
|  |   |                               |
|  | ********  | •                             |
| # H2 TURBINE #   | * H2 PUMP   |                               |
|  | STACE (NA   | STAGE THO STAGE THREE         |
|  | *****   |                               |
| EFFICIENCY (T/T) 0.870   | EFFICIENCY 0.730  | 0.728                         |
| EFFICIENCY (T/S) 0.835   | HORSEPONER 1409.  | 1407. 1402.                   |
| EFFICIENCY (T/S) 0.855 SPEED (RPW) 107143. HORSEPOHER 4218. HEAN DIA. (IM) 2.95 EFF AREA (IN2) 0.51 U/C (ACTUAL) 0.516 | SPEED (RPM) 107143.<br>SS SPEED 11885.<br>S SPEED 1058.<br>HEAD (FT) 50591.<br>DIA. (IN) 3.79 | 107143. 107143.               |
| MEAN DIA. (IN) 2.91  | S SPEED 11885.  | 1049. 1042.                   |
| MEAN DIA. (IN) 2.93<br>EFF AREA (IN2) 0.51<br>U/C (ACTUAL) 0.516<br>MAX TIP SPFFD 1493                                 | HEAD (FT) 50591.  | 50407. 50141.                 |
| U/C (ACTUAL) 0.516   | DIA. (IN) 3.79  | 3.79 3.79                     |
|  |   |                               |
| STAGES 2<br>GAMMA 1.36   | VOL. FLOW 1110.<br>HEAD COEF 0.517  | 1084. 1062.<br>0.515 0.512    |
| PRESS RATIO (T/T) 1.82   | HEAD COEF 0.517<br>FLOH COEF 0.114  | 0.515                         |
| PRESS RATIO (1/1) 1.82 PRESS RATIO (1/5) 1.87 EXIT MACH NUMBER 0.18 SPECIFIC SPEED 57.56 SPECIFIC DIAMETER 1.33        | DIAMETER RATIO 0.400  |                               |
| EXIT MACH NUMBER 0.18  | BEARING DN 3.00E-06   |                               |
| SPECIFIC DIAMETER 1.33   | SHAFT DIAMETER 28.00  |                               |
|  |   |                               |
| ******************   | *********   |                               |
| # 02 BOOST TURBINE #   | • 02 800ST PU   |                               |
| EFFICIENCY (T/T) 0.875   | FEETCHENCY  | 0.747                         |
| EFFICIENCY (T/S) 0.705   | EFFICIENCY<br>HORSEPOWER  | 39.                           |
| SPEED (RPM) 9016.  | SPEED (RPM)   | 39.<br>9016.<br>3026.<br>242. |
| MEAN DIA (IN) 4.11<br>EFF AREA (IN2) 5.88  | S SPEED   | 3026.                         |
| U/C (ACTUAL) 0.450   | HEAD (FT)<br>Dia. (in)  | 242.<br>3.34                  |
| MAX TIP SPEED 197.   | TIP SPEED   | 132.                          |
| STAGES 1   | VOL. FLOH   | 625.                          |
| GAPHA 1.36   | HEAD COEF<br>FLOH COEF  | 0.450                         |
| PRESS RATIO (T/T) 1.01 PRESS RATIO (T/S) 1.01  | FLON COEF   | 0.200                         |
|  |   |                               |
| EXIT MACH NUMBER 0.04  |   |                               |
| EXIT MACH NUMBER 0.04  SPECIFIC SPEED 91.86  SPECIFIC DIAMETER 0.77  |   |                               |
| SPECIFIC DIAMETER 0.77   |   |                               |
| ********   | ********  |                               |
| # 02 TURBINE #   | * 02 PUMP *   |                               |
| 444444444444   |   |                               |
| EFFICIENCY (T/T) 0.853<br>EFFICIENCY (T/S) 0.778   | EFFICIENCY<br>HORSEPOHER  | 0.760                         |
| SPEED (RPM) 55362.   | SPEED (RPH)   | 53362.                        |
| HORSEPONER 800. HEAN DIA (IM) 2.93 EFF AREA (IM2) 0.73   | SS SPEED<br>S SPEED   | 21723.                        |
| HEAN DIA (1H) 2.93   | S SPEED   | 1845.                         |
| EFF AREA (IN2) 0.73<br>U/C (ACTUAL) 0.417  | MEAD (FT)   | 4991.                         |
| MAX TIP SPEED 745.   | DIA. (IN)<br>TIP SPEED  | 2.62<br>610.                  |
| STAGES 1   | VOL. FLOH   | 422.                          |
| GAPMA 1.36   | HEAD COEF   | 0.431                         |
| PRESS RATIO (T/T) 1.11 PRESS RATIO (T/S) 1.12  | FLOW COEF<br>BIAMETER RATIO   | 0.155<br>0.683                |
| EXIT MACH NUMBER 0.11  |   | .39E+06                       |
| SPECIFIC SPEED 45.99   | SHAFT DIAMETER  | 26.00                         |
| SPECIFIC DIAMETER 1.34   |   |                               |
|  |   |                               |
| REGENERATOR DAT  | •   |                               |
| ***************************************  |   |                               |
| COLD SIDE HOT SI   | DE  |                               |
| DELP 48.59 55,   | 54  |                               |
| DELT 155.71 -124.<br>AREA 8.77 2.  |   |                               |
| FLOW 11.18 11.   |   |                               |
| EFFECTIVENESS 0.31   |   |                               |
| NTU 0.46   |   |                               |
| CRATIO 0.93<br>CMIN 38.95  |   |                               |
| REGEN Q 5207.88  |   |                               |
|  |   |                               |

### TABLE 48. - FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR - 50,000 LBF THRUST (COPPER GROOVED CHAMBER)

FUEL. LOX

| ***                         |                          |                | PARAMETERS            |                  |                  |
|-----------------------------|--------------------------|----------------|-----------------------|------------------|------------------|
| Cund                        | BER PRESSU               | D.C.           |                       | 1506.0           |                  |
|                             | ENGINE THR               |                |                       | 50000.           |                  |
|                             | L ENGINE F               |                |                       | 104.16           |                  |
| DEL.                        | VAC. ISP                 |                |                       | 480.0            |                  |
|                             | AT AREA                  |                |                       | 16.23            |                  |
|                             | LE AREA RA               |                |                       | 1000.0<br>143.74 |                  |
|                             | LE EXIT DI<br>NE MIXTURE |                |                       | 6.00             |                  |
| ETA (                       |                          | RAITO          |                       | 0.993            |                  |
|                             | BER COOLAN               | T DP           |                       | 601.             |                  |
|                             | BER COOLAN               |                |                       | 335.             |                  |
| NOZZI                       | LE/CHAMBER               | Q              |                       | 19840.           |                  |
|                             |                          |                | CONDITIONS            | # H H            |                  |
|                             |                          |                | e ZHOITIONS #         |                  |                  |
| MOITATZ                     | PRESS                    | TEMP           |                       | ENTHALPY         | DENSITY<br>4.37  |
| B.P. INLET                  | 18.6                     | 37.4           | 14.91<br>14.91        | -107.5<br>-103.0 | 4.37             |
| B.P. EXIT PUMP INLET        | 100.8<br>100.8           | 38.5<br>38.5   | 14.91                 | -103.0           | 4.39             |
|                             | 1577 /                   | 54.5           | 14.91                 | -24.6            | 4.54             |
| 2ND STAGE EXIT              | 3006.6                   | 69.8           | 14.91                 | 54.0             | 4.66             |
| PUMP EXII                   | 4508.4                   | 84.9           | 14.91                 | 132.6            | 4.76             |
| COLD REGEN IN               | 4463.4                   | 85.3           | 14.91                 | 132.6<br>536.0   | 4.74<br>2.88     |
| COLD REGEN EX               | 4418.7<br>4418.7         | 205.3<br>205.3 | 14.91<br>14.91        | 536.0            | 2.88             |
| COOLANT INLET               | 3817.7                   | 540.3          | 14.91                 | 1867.0           | 1.14             |
|                             | 3779.5                   | 540.5          | 0.75                  | 1867.0           | 1.13             |
| TBV EXIT                    | 1738.1                   | 550.3          | 0.75                  | 1867.0           | 0.55             |
| 02 TRB INLET                | 3779.5                   | 540.5          | 14.16                 | 1867.0           | 1.13             |
| 02 TRB EXIT                 | 3401.6                   | 529.1          | 14.16                 | 1818.0<br>1818.0 | 1.05             |
| H2 TRB INLET<br>HC TRB EXIT | 3401.6<br>1900.6         | 529.1<br>468.3 | 14.16<br>14.16        | 1570.1           | 0.70             |
| HE TRE DIFFUSER             | 1855.0                   | 468.5          | 14.16                 | 1570.1           | 0.69             |
|                             | 1836.4                   | 468.5          | 14.16                 | 1570.1           | 0.69             |
| H2 BST TRB OUT              | 1811.9                   | 467.4          | 14.16                 | 1565.3           | 0.67             |
|                             | 1778.7                   | 467.5          | 14.16                 | 1565.3           | 0.66             |
|                             | 1760.9                   | 467.6<br>466.9 | 14.16<br>14.16        | 1565.3<br>1562.7 | 0.65             |
|                             | 1749.6<br>1746.8         | 466.9          | 14.16                 | 1562.7           | 0.65             |
| HZ TANK PRESS               | 18.6                     | 476.8          | 0.0250                | 1578.0           | 0.0074           |
| GOX HEAT EXCH IN            |                          | 471.0          | 14.88                 | 1578.0           | 0.64             |
| GOX HEAT EXCH OUT           | 1729.4                   | 470.7          | 14.88                 | 1576.6           | 0.64             |
| HOT REGEN IN                | 1729.4                   | 470.7          | 14.88                 | 1576.6<br>1172.5 | 0.64<br>0.79     |
| HOT REGEN EX                | 1677.5<br>1677.5         | 365.3<br>365.3 | 14.88<br>14.88        | 1172.5           | 0.79             |
| FSOV INLET<br>FSOV EXIT     | 1635.6                   | 365.4          | 14.88                 | 1172.5           | 0.78             |
| CHAMBER INJ                 | 1619.2                   | 365.4          | 14.88                 | 1172.5           | 0.77             |
| CHAMBER                     | 1506.0                   |                |                       |                  |                  |
|                             |                          |                | CONDITIONS            |                  | DOME ! THE       |
| MOLTATE                     | PRESS                    |                |                       | ENTHALPY<br>61.9 | DENSITY<br>70.99 |
| B.P. INLET<br>B.P. EXIT     | 16.0<br>135.2            | 162.7<br>165.3 | 89.4<br>89.4          | 62.3             | 70.84            |
| PUMP INLET                  | 135.2                    | 165.3          | 89.4                  | 62.3             | 70.84            |
| PUMP EXIT                   | 2439.0                   | 175.5          | 89.4                  | 70.1             | 71.39            |
| 02 TANK PRESS               | 16.0                     | 400.0          | 0.152                 | 204.7            | 0.12             |
| OSOV INLET                  | 2414.6                   | 175.6          | 13.4                  | 70.1             | 71.36            |
| OSOV EXIT                   | 1690.2                   | 178.4          | 13.4                  | 70.l             | 70.22<br>71.36   |
| OCV INLET                   | 2414.6                   | 175.6<br>178.4 | 75.9<br>75.9          | 70.1<br>70.1     | 70.22            |
| OCV EXIT<br>CHAMBER INJ     | 1690.2<br>1673.3         | 178.4          | 89.3                  | 70.1             | 70.19            |
| CHAMBER INS                 | 1506.0                   | •              |                       |                  |                  |
|                             |                          | * VALVE DA     | ITA .                 |                  |                  |
|                             |                          |                | <b>6</b> . <b>6</b> . | * BUALCC         |                  |
| VALVE                       | DELTA P                  |                | FLOW<br>0.75          | % BYPASS<br>5.00 |                  |
| TBV                         | 2041.<br>42.             |                |                       | 3.00             |                  |
| FSOV<br>OCV                 | 724.                     |                |                       |                  |                  |
|                             |                          | INJECTOR       |                       |                  |                  |
|                             |                          |                |                       |                  |                  |
| INJECTOR                    | DELTA P                  | AREA<br>2.58   | FLOH                  |                  |                  |
| 616                         |                          |                | 1 4 . 00              |                  |                  |

2.38

89.28

TABLE 48. — FULL-EXPANDER ENGINE WITH HYDROGEN REGENERATOR — 50,000 LBF THRUST (COPPER GROOVED CHAMBER) (CONTINUED)

|   | ERY PERFORMANCE DATA          |                |                 |                           |
|---|-------------------------------|----------------|-----------------|---------------------------|
| ***************   | *****                         | ******         |                 |                           |
| * H2 BOOST TURBINE *  |                               | BOOST PU       |                 |                           |
| EFFICIENCY (T/T) 0.770  |                               | ******         |                 |                           |
| EFFICIENCY (T/S) 0.272  | EFFICIEN<br>HORSE <b>PO</b> N | ER             | 96.             |                           |
| SPEED (RPH) 29226.  | SPEED                         | (RPH)          | 29226.          |                           |
| MEAN DIA (IN) 5.44<br>EFF AREA (IN2) 5.02                       | S SPEED<br>HEAD               |                | 3045.<br>2701.  |                           |
| U/C (ACTUAL) 0.376  | HEAD<br>DIA.                  | (IN)           | 3.44            |                           |
| MAX TIP SPEED 290.  | TIP SPEE                      | D              | 437.            |                           |
| STAGES 1 GAMMA 1.38   | VOL. FLOI<br>HEAD CORE        | H<br>F         | 1524.<br>0.450  |                           |
| PRESS RATIO (T/T) 1.01  | FLOM COE                      | ·              | 0.201           |                           |
| PRESS RATIO (T/S) 1.04  |                               |                |                 |                           |
| HORSEPOHER 96.<br>EXIT MACH NUMBER 0.17                         |                               |                |                 |                           |
| SPECIFIC SPEED 103.11   |                               |                |                 |                           |
| SPECIFIC DIAMETER 0.46  |                               |                |                 |                           |
| ********  | •••                           | ******         | 1               |                           |
| # H2 TURBINE 4  |                               | 2 PUMP .       |                 |                           |
| *44446664   |                               |                |                 |                           |
|   |                               |                |                 | STAGE THREE               |
| EFFICIENCY (T/T) 0.885<br>EFFICIENCY (T/S) 0.842                | EFFICIENCY                    | 0.754          | 0.752           | 0.750                     |
| EFFICIENCY (T/S) 0.842  | HORSEPOHER                    | 1653.          | 1656.           | 0.750<br>1658.<br>100000. |
| HORSEPOHER 4967.  | SPEED (RPM) 16<br>SS SPEED 1  | 2000.<br>2013. | 100000.         | 100000.                   |
| MEAN DIA. (1H) 3.08<br>EFF AREA (IN2) 0.69                      | S SPEED                       | 1223.          | 1208.           | 1196.                     |
| EFF AREA (IN2) 0.69<br>U/C (ACTUAL) 0.540                       |                               | 5957.          | 45952.          | 45895.                    |
|   | DIA. (IN)<br>TIP SPEED        | 3.95<br>1718.  | 3.95<br>1710.   | 3.93<br>1718.             |
| STAGES 2  | VOL. FLOH                     | 1472.          | 1436.           | 1405.                     |
| GAPMA 1.58 PRESS RATIO (T/T) 1.79                               |                               | 4.501          | 0.501           | 0.500                     |
| PRESS RATIO (T/T) 1.79 PRESS RATIO (T/S) 1.85                   | DIAMETER RATIO                | 0.124<br>0.441 |                 |                           |
| EXIT MACH MUMBER 0.20   | BEARING DH 3.0                | 9€+06          |                 |                           |
| SPECIFIC SPEED 66.39<br>SPECIFIC DIAMETER 1.22                  | SHAFT DIAMETER                | 30.00          |                 |                           |
| SPECIFIC DIAMETER 1.22  |                               |                |                 |                           |
|   |                               | *******        |                 |                           |
| * OZ BOOST TURBINE «  |                               | OOST PUM       |                 |                           |
| EFFICIENCY (T/T) 0.865  | EFFICIENC                     | v              | 0.764           |                           |
| EFFICIENCY (T/S) 0.652  | EFFICIENC<br>HORSEPONE        | R              | 52.             |                           |
| SPEED (RPH) 7808.   | SPEED (                       | RPH)           | 7808.           |                           |
| EFF AREA (IN2) 7.50   | S SPEED<br>HEAD               | (FT)           | 3026.<br>242.   |                           |
| MEAN DIA (IN) 4.11<br>EFF AREA (IN2) 7.50<br>U/C (ACTUAL) 0.390 | HEAD<br>DIA.                  | (INI)          | 5.86            |                           |
| MAX TIP SPEED 176.<br>STAGES                                    | TIP SPEED                     |                | 132.            |                           |
| GAMMA 1.38  | VOL. FLON<br>HEAD COEF        |                | 567.<br>0.450   |                           |
| PRESS RATIO (T/T) 1.01  | HEAD COEF<br>FLOH COEF        |                | 0.200           |                           |
| PRESS RATIO (T/S) 1.01<br>HORSEPOHER 52.                        |                               |                |                 |                           |
| EXIT MACH HUMBER 0.05   |                               |                |                 |                           |
| SPECIFIC SPEED 84.96  |                               |                |                 |                           |
| SPECIFIC DIAMETER 0.71  |                               |                |                 |                           |
|   | ****                          |                |                 |                           |
| • OZ TURBINE •  |                               | PUMP .         |                 |                           |
| EFFICIENCY (T/T) 0.887  |                               | ,              | 0.769           |                           |
| EFFICIENCY (T/S) 0.832  | EFF1C1ENC                     | t              | 982.            |                           |
| SPEED (RPH) 44714,  | SPEED (A                      |                | 44714.          |                           |
| HORSEPOMER 982. HEAN DIA (IN) 3.08 EFF AREA (IN2) 1.01          | 22 SPEED<br>22 SPEED          |                | 21019.<br>1885. |                           |
| EFF AREA (IN2) 1.01   | MEAN (                        | ET1            | 4645.           |                           |
| U/C (ACTUAL) 0.543  | DIA. (                        | (N)            | 3.01            |                           |
| MAX TIP SPEED 679.<br>STAGES 2                                  | TIP SPEED<br>VOL. FLON        |                | 587.<br>562.    |                           |
| GA447 1.28  | HEAD CORF                     |                | 0.434           |                           |
| PRESS RATIO (T/T) 1.11  | FLOM CORF                     |                | 0.157           |                           |
| PRESS RATIO (T/S) 1.12<br>EXIT MACH HUMBER 0.09                 | DIAMETER R<br>BEARING ON      | ATIO           | 0.684           |                           |
| SPECIFIC SPEED 78.07  | SHAFT DIAM                    |                | 00.02           |                           |
| SPECIFIC DIAMETER 1.06  |                               |                |                 |                           |
|   |                               |                |                 |                           |
| REGEMERATOR DATA  |                               |                |                 |                           |
| 444444444444444444444444444444444444444                         | _                             |                |                 |                           |
| COLD SIDE HOT SID<br>DELP 44.64 51.8                            |                               |                |                 |                           |
| DELT 119.92 ~105.3  |                               |                |                 |                           |
| AREA 1.87 5.7   | 1                             |                |                 |                           |
| FLOM 14.91 14.81<br>EFFECTIVENESS 0.51                          | 3                             |                |                 |                           |
| NTU 0.46  |                               |                |                 |                           |
| CRATIO 0.88   |                               |                |                 |                           |
| CMIN 50.14<br>REGEN Q 6012.47                                   |                               |                |                 |                           |
| 1012.37   |                               |                |                 |                           |

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#### APPENDIX C THROTTLED CYCLES

Throttled cycle data are presented in Tables 49 through 56.

TABLE 49. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 100% OF DESIGN THRUST LEVEL

| SNGINE 1007                      |                          |                    | E PARAMETER                  |                           |                |
|----------------------------------|--------------------------|--------------------|------------------------------|---------------------------|----------------|
| **                               |                          |                    | **********                   |                           |                |
|                                  | BER PRESSU               |                    |                              | 1612.0                    |                |
|                                  | ENGINE THR<br>. VAC. ISP |                    |                              | 20000.<br>480.0           |                |
| TOTA                             | AL ENGINE F              |                    |                              | 41.7                      |                |
|                                  | DAT AREA<br>ZLE AREA RA  | TIO                |                              | 6.066<br>1000.8           |                |
|                                  | INE MIXTURE              |                    |                              | 6.00                      |                |
|                                  | MBER/NOZZLE              |                    |                              | 583.                      |                |
| CHA!<br>ETA                      | IBER/NOZZLE              | COOLANT            | DI                           | 1018.<br>0.993            |                |
|                                  | MBER/NOZZLE              | 0                  |                              | 11170.                    |                |
|                                  |                          |                    | CONDITIONS                   | ***                       |                |
|                                  |                          |                    | * ZMCITIONS                  | ENTHALPY                  | DENSITY        |
| STATION<br>B.P. INLET            | PRESS<br>18.6            | TEMP<br>37.4       | FLOH<br>5.96                 | -107.5                    | 4.37           |
| B.P. EXIT                        | 100.9                    | 38.5               | 5.96                         | -103.0                    | 4.39           |
| PUMP INLET                       | 100.9                    | 38.5<br>70.3       | 5.96<br>5.96                 | -103.0<br>34.1            | 4.39<br>4.36   |
| 1ST STAGE EXIT<br>JBV INLET      | 2177.3<br>2133.8         | 70.7               | 2.98                         | 34.1                      | 4.33           |
| JBV EXIT                         | 1813.9                   | 73.1               | 2.98                         | 34.1                      | 4.11           |
| 2ND STAGE EXIT                   | 3487.5                   | 90.9               | 2.98<br>2.98                 | 123.8<br>210.3            | 4.35<br>4.37   |
| PUMP EXIT                        | 4762.3<br>4714.6         | 110.4<br>110.8     | 2.70                         | 210.3                     | 4.35           |
| COOLANT EXIT                     | 4131.6                   | 1128.8             | 2.98                         | 3965.9                    | 0.63           |
| TBV INLET                        | 4090.3                   | 1129.1             | 0.15<br>0.15                 | 3965.9<br>3965.9          | 0.62<br>0.30   |
| TBV EXIT                         | 1899.9<br>4090.3         | 1129.1             | 2.03                         | 3965.9                    | 0.62           |
| LOX TRB EXIT                     | 3612.5                   | 1101.3             | 2.83                         | 3856.6                    | 0.57           |
| H2 TRB INLET                     | 3612.5                   | 1101.3<br>976.9    | 2. <b>83</b><br>2. <b>83</b> | 3856.6<br>33 <b>8</b> 2.6 | 0.57<br>0.37   |
| H2 TRB EXIT                      | 2011.4<br>1990.1         | 977.1              | 2.83                         | 3382.6                    | 0.36           |
| H2 BST TRB IN                    | 1970.2<br>1947.4         | 977.2              |                              | 3382.6                    | 0.36           |
| H2 BST TRB EXIT                  |                          | 974.6<br>974.7     | 2.83<br>2.83                 | 3373.1<br>3375.1          | 0.36           |
| H2 BST TRB DIFF<br>O2 BST TRB IN | 1923.1                   | 974.B              | 2.83                         | 3373.1                    | 0.35           |
| OZ BST TRB EXIT                  | 1911.2                   | 973.4              | 2.83                         | 3367.9                    | 0.35<br>0.35   |
| 02 BST TRB DIFF                  |                          | 973.4              | 2.83<br>0.0048               | 3367.9<br>3398.0          | 0.0035         |
| H2 TANK PRESS GOX HEAT EXCH IN   |                          | 382.1              | 2.97                         | 3398.0                    | 0.35           |
| GOX HEAT EXCH OU                 | T 1890.4                 | 981.4              | 2.97                         | 3395.2                    | 0.35<br>0.35   |
| MIXER HOT IN<br>MIXER COLD IN    | 1890.4<br>1813.9         | 981.4<br>73.1      | 2.97<br>2.98                 | 33 <b>95.</b> 2<br>34.1   | 4.11           |
| MIXER OUT                        | 1795.8                   | 508.0              | 5.95                         | 1713.8                    | 0.62           |
| FSV INLET                        | 1795.8                   | 508.0              | 5.95                         | 1713.8                    | 0.62<br>0.60   |
| FSV EXIT<br>CHAMBER INJ          | 1750.9<br>1733.4         | 508.2<br>508.2     | 5.95<br>5.95                 | 1713.8<br>1713.8          | 0.60           |
| CHAMBER                          | 1612.0                   |                    |                              |                           |                |
|                                  |                          |                    | CONDITIONS                   |                           | DENSITY        |
| STATION<br>B.P. INLET            | PRESS<br>lb.0            | TEMP<br>152.7      | FLON<br>35.77                | 61.1                      | 71.17          |
| B.P. EXIT                        | 135.2                    | 163.3              |                              | 61.5                      | 71.20          |
| PUMP INLET                       | 135.2                    | 163.3              | 35.77<br>35.77               | 61.5<br>70.1              | 71.20<br>71.65 |
| PUMP EXIT 02 TANK PRESS          | 2612.1<br>16.0           | 174.9<br>400.0     | 0.86                         | 204.8                     | 0.12           |
| POSV INLET                       | 2586.0                   | 175.0              | 5.17                         | 70.1                      | 71.61          |
| POSV EXIT                        | 1795.6                   | 178.0<br>175.0     | 5.17<br>30.55                | 70.1<br>70.1              | 70.38<br>71.61 |
| OCV INLET                        | 2586.0<br>1811.7         | 178.0              |                              | 70.1                      | 70.41          |
| PRIMARY INJ                      | 1762.1                   | 178.2              |                              | 70.1                      | 70.33          |
| SECONDARY INJ                    | 1775.2<br>1612.0         | 178.1              | 30.55                        | 70.1                      | 70.35          |
| CHAMBER                          |                          |                    |                              |                           |                |
|                                  |                          | _VE DATA           |                              |                           |                |
| VALVE                            | DELTA P                  | 4REA               |                              | BYPASS                    |                |
| JBV                              | 358.                     |                    |                              | 49. <b>98</b><br>5.02     |                |
| TBV<br>FSV                       | 2190.<br>•5.             |                    | 0.15<br>5. <del>95</del>     | 3.02                      |                |
| POSV                             | 79 <b>0.</b><br>774.     | 1.032              | 5.17                         |                           |                |
|                                  | : 4.                     | ECTOR DATA         | 4                            |                           |                |
| • FUEL                           |                          | XO +               |                              |                           |                |
|                                  | - 5                      | : MARY             | SECOND                       |                           |                |
| DELP MAN 18.                     |                          | 6 <b>8</b><br>3.37 | 18.14<br>163.21              |                           |                |
| DELP INJ 103.<br>AREA 1.         | 14                       | 08                 | 0.43                         |                           |                |
| FLOH 5.                          |                          | 5.17               | 30.55                        |                           |                |
|                                  |                          |                    |                              |                           |                |

TABLE 49. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 100% OF DESIGN THRUST LEVEL (CONTINUED)

|  |          |          | PERFORMANCE DATE                 |                    |               |             |
|--|----------|----------|----------------------------------|--------------------|---------------|-------------|
|  | ******   |          | *****                            |                    |               |             |
| *******  |          |          | ****                             | ******             |               |             |
|  |          |          | # H2                             | BOOST PA           | MP =          |             |
|  | ******** |          |                                  | *******            |               |             |
| EFFICIENCY<br>HORSEPOHER<br>SPEED (RPM)  | 0.95     | 7        |                                  |                    |               |             |
| HODGEBOHED   | 70       | •        | FLLICIE                          | INCY<br>HER        | 70            |             |
| HUKSEPUNEK   | 36       | •        | HUKSEPU                          | MEK                | 38.           |             |
| SPEED (RPM)  | 46158    | •        | SPEED                            | (RPM)              | 46158.        |             |
| MEAN DIA (IN)  | 1.90     | 0        | S SPEED                          | )                  | 3839.         |             |
| EFF AREA (IN2)   | 1.4      | 5        | HEAD                             | (FT)               | 2703.         |             |
| U/C (IDEAL)  | 0.512    | 2        | DIA.                             | (IN)               | 2.18          |             |
| MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED   | 382      |          | TIP SPE                          | (FT)<br>(IN)<br>ED | 439.          |             |
|  |          |          | VUL. FL                          | UM                 |               |             |
| CELTA H (ACT)  | 9.5      | <b>b</b> | HEAD CO                          | EF<br>EF           | 8.452         |             |
| GA <b>MMA</b>  | 1.43     | 3        | FLOW CO                          | EF                 | 0.201         |             |
| PRESS RATIO (T/  | T) 1.01  | 1        |                                  |                    |               |             |
|  |          |          |                                  |                    |               |             |
| ********   |          |          |                                  | ******             |               |             |
| # H2 TURBIN  | E +      |          |                                  | H2 PUT             |               |             |
| *********  |          |          |                                  | ******             |               |             |
|  |          | STAGE S  |                                  |                    |               | STAGE THREE |
|  | 31702    | STAGE 2  | _                                |                    |               |             |
| EEEICIENCA   | 0.005    | 0.00     | EEEICIENCY -                     | 0 (63              | A (2)         | 0 /2/       |
| HODGEBOHER   | 0.803    | 0.606    | FLLICIENCE                       | 0.842              | 730           | 0.626       |
| HURSEPUNER   | 950.     | 948.     | HURSEPUWER                       | 1155.              | 3/8.          | 365.        |
| SPEED (RPM)  | 124983.  | 124983.  | SPEED (RPM)                      | 124983.            | 124983.       | 124983.     |
| MEAN DIA (IN)  | 3.47     | 3.47     | S SPEED                          | 731.               | 730.          | 744.        |
| EFF AREA (IN2)   | 0.21     | 0.26     | HEAD (FT)                        | 68 <b>442</b> .    | 43325.        | 42101.      |
| U/C (IDEAL)  | 0.493    | 0.494    | DIA. (IN)                        | 3.49               | 3.02          | 3.02        |
| MAX TIP SPEED  | 1895.    | 1895.    | TIP SPEED                        | 2012.              | 1647.         | 1647.       |
| DELTA H  | 237.     | 237.     | VOL. FLOW                        | 613.               | 307.          | 306.        |
| GAMMA (ACT)  | 1.43     | 1.43     | HEAD COEF                        | 0.544              | 0.514         | 0.499       |
| EFFICIENCY HORSEPOHER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED CELTA H GAMMA (ACT) PRESS RATIO(T/T | 1.33     | 1.35     | FLOW COEF                        | 0.092              | 0.092         | 0.093       |
| ********   |          |          |                                  |                    |               |             |
| • 02 800ST   |          |          |                                  | BOOST PUR          |               |             |
| ********   |          |          |                                  |                    |               |             |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 0.959    |          | SEETCIEN                         | acv                | 0.764         |             |
| PUBSEBURED   | 71       |          | EFFICIEN<br>HORSEPO              | 4C 1               | 21.           |             |
| COEED (DOM)  | 1272/    |          | HORSEPON<br>SPEED<br>S SPEED     | (DDM)              | 12724         |             |
| SPEED (KPH)  | 12324.   |          | SPEED                            | (RPH)              | 12324.        |             |
| TEAN DIA (IN)  | 5.20     |          | 5 SPEED                          | . == .             | 5024.         |             |
| EFF AREA (IN2)   | 2.02     |          | HEAD                             | (FT)               | 241.          |             |
| SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES SPETA H (ACT)                                      | 0.512    |          | HEAD<br>DIA.<br>TIP SPEE         | (IN)               | 2.44          |             |
| MAX TIP SPEED  | 280.     |          | TIP SPEE                         | D                  | 131.          |             |
| STAGES   | ì.       |          | VOL. FLO                         | )H                 | 226.<br>0.451 |             |
| D.C  | 3        |          | HEAD COE                         | F                  | 0.451         |             |
| JAMMA  | 1.43     |          | VOL. FLO<br>HEAD COE<br>FLOW COE | F                  | 0.200         |             |
| PRESS RATIO (T/T   | 1.31     |          |                                  |                    |               |             |
| ********   |          |          |                                  | ******             |               |             |
| # 02 TURBINE   |          |          |                                  | 2 PURP =           |               |             |
| ********   |          |          |                                  | *****              |               |             |
|  |          |          |                                  |                    | 9.740         |             |
| EFFICIENCY<br>HORSEPOWER   | 439.     |          | EFFICIEN<br>HORSEPON             | FR.                | 438           |             |
| SPEED (RPM)  | 74nnse   |          | HORSEPOW<br>SPEED<br>S SPEED     | (RPM)              | 74009         |             |
| GPEED (RPM) MEAN DIA (IN)  | 3.47     |          | C CPEED                          |                    | 1870          |             |
| SEE ADEA (IN)  | 0.47     |          | 2 24550                          | (ET)               | 4074          |             |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED   | 0.410    |          | HEAD<br>DIA.                     | (144               | 47/8.         |             |
| TAY TID COCED  | 0.430    |          | JIA.                             | CIM)               | 1.90          |             |
| TACES  | 1122.    |          | TIP SPEE                         |                    | 615.          |             |
| TAGES  |          |          | VOL. FLO                         | H -                | 224.          |             |
| TELTA H (ACT)<br>BAMMA   | 109.27   |          | HEAD COE<br>FLOW COE             | -                  | 0.423         |             |
|  |          |          | FLOW COE                         | ۲                  | 0.157         |             |
| PESS RATIO (T/T  | 1 :.15   |          |                                  |                    |               |             |
|  |          |          |                                  |                    |               |             |

TABLE 50. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 50% OF DESIGN THRUST LEVEL

| ENGINE | PERFORMANCE | PARAMETERS |
|--------|-------------|------------|
|        |             |            |

| CHAMBER PRESSURE          | 801.9  |
|---------------------------|--------|
| VAC ENGINE THRUST         | 10000. |
| DEL. VAC. ISP             | 479.7  |
| TOTAL ENGINE FLOW RATE    | 20.8   |
| THROAT AREA               | 6.066  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.00   |
| CHAMBER/NOZZLE COOLANT DP | 547.   |
| CHAMBER/NOZZLE COOLANT DT | 730.   |
| ETA C*                    | 0.993  |
| CHAMBER / NO.271 F 0      | 6340.  |

## ENGINE STATION CONDITIONS

|                   | *****  | ********     | ********* | * # * *  |         |
|-------------------|--------|--------------|-----------|----------|---------|
|                   | * FUEL | _ SYSTEM CON | DITIONS * |          |         |
| STATION           | PRESS  | TEMP         | FLON      | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4         | 2.98      | -107.5   | 4.37    |
| B.P. EXIT         | 66.0   | 38.2         | 2.98      | -104.5   | 4.38    |
| PUMP INLET        | 66.0   | 38.2         | 2.98      | -104.5   | 4.38    |
| 1ST STAGE EXIT    | 1345.6 | 60.5         | 2.98      | -13.0    | 4.27    |
| JBV INLET         | 1343.4 | 60.6         | 0.66      | -13.0    | 4.27    |
| JBV EXIT          | 908.0  | 63.3         | 0.66      | -13.0    | 3.89    |
| 2ND STAGE EXIT    | 1998.7 | 71.4         | 2.33      | 33.1     | 4.25    |
| PUMP EXIT         | 2627.5 | 81.8         | 2.33      | 77.3     | 4.24    |
| COOLANT INLET     | 2597.6 | 82.0         | 2.33      | 77.3     | 4.22    |
| COOLANT EXIT      | 2050.2 | 811.8        | 2.33      | 2803.9   | 0.45    |
| TBV INLET         | 2014.9 | 812.0        | 0.71      | 2803.9   | 0.44    |
| TBV EXIT          | 997.3  | 818.4        | 0.71      | 2803.9   | 0.22    |
| LOX TRB INLET     | 2014.9 | 812.0        | 1.61      | 2803.9   | 0.44    |
| LOX TRB EXIT      | 1788.8 | 792.9        | 1.61      | 2731.2   | 0.40    |
| H2 TRB INLET      | 1788.8 | 792.9        | 1.61      | 2731.2   | 0.40    |
| H2 TRB EXIT       | 1051.3 | 712.3        | 1.61      | 2431.9   | 0.27    |
| H2 TRB DIFF       | 1041.7 | 712.4        | 1.61      | 2431.9   | 0.27    |
| H2 BST TRB IN     | 1032.9 | 712.4        | 1.61      | 2431.9   | 0.26    |
| H2 BST TRB EXIT   | 1022.6 | 710.9        | 1.61      | 2426.4   | 0.26    |
| H2 BST TRB DIFF   | 1020.4 | 710.9        | 1.61      | 2426.4   | 0.26    |
| 02 BST TRB IN     | 1011.8 | 711.0        | 1.61      | 2426.4   | 0.26    |
| 02 BST TRB EXIT   | 1006.4 | 710.2        | 1.61      | 2423.4   | 0.26    |
| 02 BST TRB DIFF   | 1006.1 | 710.2        | 1.61      | 2423.4   | 0.26    |
| H2 TANK PRESS     | 18.6   | 749.3        | 0.0032    | 2540.0   | 0.0047  |
| GOX HEAT EXCH IN  | 997.3  | 743.4        | 2.32      | 2540.0   | 0.24    |
| GOX HEAT EXCH OUT | 989.1  | 743.0        | 2.32      | 2538.2   | 0.24    |
| MIXER HOT IN      | 989.1  | 743.0        | 2.32      | 2538.2   | 0.24    |
| MIXER COLD IN     | 908.0  | 63.3         | 0.66      | -13.0    | 3.89    |
| MIXER OUT         | 907.1  | 584.2        | 2.98      | 1976.3   | 0.28    |
| FSV INLET         | 907.1  | 584.2        | 2.98      | 1976.3   | 0.28    |
| FSV EXIT          | 881.4  | 584.3        | 2.98      | 1976.3   | 0.27    |
| CHAMBER INJ       | 871.8  | 584.3        | 2.98      | 1976.3   | 0.27    |
| CHAMBER           | 801.9  |              |           |          |         |
|                   |        |              |           |          |         |

|               | * OXY  | GEN SAZIEM | CONDITION | > <b>*</b> |         |
|---------------|--------|------------|-----------|------------|---------|
| STATION       | PRESS  | TEMP       | FLOH      | ENTHALPY   | DENSITY |
| B.P. INLET    | 16.0   | 162.7      | 17.90     | 61.1       | 71.17   |
| B.P. EXIT     | 84.3   | 163.1      | 17.90     | 61.3       | 71.17   |
| PUMP INLET    | 84.3   | 163.l      | 17.90     | 61.3       | 71.17   |
| PUMP EXIT     | 1800.0 | 172.6      | 17.90     | 67.9       | 71.28   |
| 02 TANK PRESS | 16.0   | 400.0      | 0.03      | 204.8      | 0.12    |
| POSY INLET    | 1793.4 | 172.6      | 5.20      | 67.9       | 71.27   |
| POSV EXIT     | 989.0  | 175.6      | 5.20      | 67.9       | 69.97   |
| OCV INLET     | 1793.4 | 172.6      | 12.67     | 67.9       | 71.27   |
| OCV EXIT      | 836.5  | 176.2      | 12.67     | 67.9       | 69.72   |
| PRIMARY INJ   | 954.8  | 175.7      | 5.20      | 67.9       | 69.91   |
| SECONDARY INJ | 830.2  | 176.2      | 12.67     | 67.9       | 69.71   |
| CHAMBER       | 801.9  |            |           |            |         |
|               |        |            |           |            |         |

|       | VAL     | VE DATA |       |          |
|-------|---------|---------|-------|----------|
|       | ***     | *****   |       |          |
| VALVE | DELTA P | AREA    | FLOM  | % BYPASS |
| JBV   | 436.    | 0.023   | 0.66  | 22.00    |
| TBV   | 1018.   | 0.072   | 0.71  | 30.63    |
| FSV   | 26.     | 1.653   | 2.98  |          |
| POSV  | 804.    | 0.032   | 5.20  |          |
| OCV   | 957.    | 0.073   | 12.67 |          |

|          | INJECTOR DATA |         |        |  |  |
|----------|---------------|---------|--------|--|--|
|          | * FUEL *      | *       | OXID * |  |  |
|          |               | PRIMARY | SECOND |  |  |
| DELP MAN | 10.05         | 16.99   | 3.15   |  |  |
| DELP INJ | 59.81         | 152.91  | 28.32  |  |  |
| AREA     | 1.14          | 0.08    | 0.43   |  |  |
| FLON     | 2.98          | 5.20    | 12.67  |  |  |

TABLE 50. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 50% OF DESIGN THRUST LEVEL (CONTINUED)

|  | * TURBOMA | CHINERY PI | KNANKKANNANKA<br>ERFORMANCE DATA<br>KANKKANKANANA | . *          |         |             |
|--|-----------|------------|---|--------------|---------|-------------|
| *******  |           |            |   | *****        | ***     |             |
| * H2 BOOST T   |           |            |   | BOOST PU     |         |             |
| * 112 00031 1  |           |            |   | ******       |         |             |
| EFFICIENCY   |           |            | EFFICIEN  |              |         |             |
| EFFICIENCY   | 0.784     |            | HORSEPON  |              | 13.     |             |
| HORSEPOWER SPEED (RPM)   | 13.       |            |   | (RPM)        |         |             |
|  | 30494.    |            |   |              | 2148.   |             |
| MEAN DIA (IN)  |           |            | S SPEED   |              | 1560.   |             |
| EFF AREA (IN2)   | 1.45      |            | HEAD<br>DIA.                                      | (71)         |         |             |
| U/C (IDEAL)  |           |            |   |              | 2.18    |             |
| MAX TIP SPEED  |           |            | TIP SPEE  |              | 290.    |             |
| STAGES   | 1.        |            | VOL. FLO  |              | 306.    |             |
| DELTA H (ACT)  |           |            | HEAD COE  |              | 0.597   |             |
| GAMMA  | 1.39      |            | FLOW COE  | F            | 0.153   |             |
| PRESS RATIO (T/T   | 1.01      |            |   |              |         |             |
|  |           |            |   |              |         |             |
| ********   |           |            |   | ******       |         |             |
| * H2 TURBINE   |           |            |   | H2 PUMP      |         |             |
| ********   |           |            |   | *******      |         |             |
|  |           | STAGE 2    |   |              |         | STAGE THREE |
|  | *****     | *****      | **  | ****         | ******* | ********    |
| EFFICIENCY   | 0.766     | 0.775      | EFFICIENCY  | 0.602        | 0.615   | 0.620       |
| HORSEPOWER   | 347.      | 336.       | HORSEPOWER  | 386.         | 152.    | 145.        |
| SPEED (RPM)  | 92001.    | 92001.     | SPEED (RPM)                                       | 92001.       | 92001.  | 92001.      |
| MEAN DIA (IN)  | 3.47      | 3.47       | S SPEED   | 547.         | 796.    | 818.        |
| EFF AREA (IN2)   | 0.21      | 0.26       | HEAD (FT)   | 42849.       | 22073.  | 21323.      |
| U/C (IDEAL)  | 0.442     | 0.452      | DIA. (IN)   | 3.69         | 3.02    | 3.02        |
| MAX TIP SPEED  | 1395.     | 1395.      | TIP SPEED   | 1481.        | 1212.   | 1212.       |
| DELTA H  | 152.      | 147.       | VOL. FLOW   | 313.         | 245.    | 246.        |
| GAMMA (ACT)  | 1.39      | 1.39       | HEAD COEF   | 0.629        | 0.483   | 0.467       |
| EFFICIENCY HORSEPOWER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 1.33      | 1.35       | FLOW COEF   | 0.064        | 0.100   | 0.102       |
|  |           |            |   |              |         |             |
| *******  | *****     |            | ***   | ******       | ***     |             |
| * 02 BOOST T   | URBINE *  |            | * 02  | BOOST PU     | MP #    |             |
|  | *******   |            | ****  | ******       | ***     |             |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 0.784     |            | EFFICIEN  | ICY          | 0.674   |             |
| HORSEPOWER   | 7.        |            | HORSEPON  | IER .        | 7.      |             |
| SPEED (RPM)  | 8074.     |            | SPEED   | (RPM)        | 8074.   |             |
| MEAN DIA (IN)  | 5.20      |            | S SPEED   |              | 2129.   |             |
| FFF AREA (IN2)   | 2.02      |            | HEAD<br>DIA.                                      | (FT)         | 138.    |             |
| U/C (IDEAL)  | 0.512     |            | DIA.  | (IN)         | 2.44    |             |
| SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES  | 183.      |            | TIP SPEE  |              | 86.     |             |
| STAGES   | 1.        |            | VOL. FLO  | )W           | 113.    |             |
| DELTA H (ACT)  |           |            | HEAD COE  |              | 0.602   |             |
| GAMMA  | 1.39      |            | FLOW COE  |              | 0.153   |             |
| PRESS RATIO (T/T   |           |            | _   |              |         |             |
| 1 NESS AA110 1171  | ,         |            |   |              |         |             |
| *********  | **        |            | ***   |              |         |             |
| * 02 TURBINE   |           |            | . (   | 2 PUMP #     |         |             |
| ********   |           |            |   | *******      |         |             |
| EFFICIENCY   | 0.777     |            | EFF I CIEN  | 4CY          | 0.679   |             |
| HORSEPOWER   | 166.      |            | HODSEDOR  | JFD.         | 166.    |             |
| SPEED (RPM)  |           |            | SPEED   | (RPM)        | 56756.  |             |
| MEAN DIA (IN)  | 3.47      |            | S SPEED   |              | 1334.   |             |
| EFF AREA (IN2)   |           |            |   |              | 3466.   |             |
| U/C (IDEAL)  |           |            | DIA.  | (FT)<br>(1N) | 1.90    |             |
| MAX TIP SPEED  | 860.      |            | TIP SPEE  |              | 472.    |             |
| STAGES   | 1.        |            | VOL. FLO  |              | 113.    |             |
|  |           |            | HEAD COE  |              | 0.502   |             |
| DELTA H (ACT)  | 1.39      |            | FLOW COE  |              | 0.103   |             |
| GAMMA PRESS RATIO (T/T   |           |            | FLUM CUE  | -•           | 5.103   |             |
| PRESS RATIO LIVI   | 1.13      |            |   |              |         |             |

## TABLE 51. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 10% OF DESIGN THRUST LEVEL

| ENGINE   | PERFORMANCE | PARAMETERS  |
|----------|-------------|-------------|
| ******** | **********  | *********** |

| CHAMBER PRESSURE          | 158.2  |
|---------------------------|--------|
| VAC ENGINE THRUST         | 2008.  |
| DEL. VAC. ISP             | 478.9  |
| TOTAL ENGINE FLON RATE    | 4.2    |
| THROAT AREA               | 6.066  |
| NOZZLE AREA RATIO         | 1008.8 |
| ENGINE MIXTURE RATIO      | 6.00   |
| CHAMBER/NOZZLE COOLANT DP | 214.   |
| CHAMBER/NOZZLE COOLANT DT | 786.   |
| ETA C*                    | 0.993  |
| CHAMPER /MOZZI E IO       | 1740   |

|   |   |                                  | CONDITIONS             |          |         |
|---|---|----------------------------------|------------------------|----------|---------|
|   |   |                                  | * ZNOITIONC            |          |         |
| STATION   |   |                                  | FLON                   | ENTHALPY | DENSITY |
| B.P. INLET  | 18.6                                      | 37.4                             | 0.60                   | -107.5   | 4.37    |
| B.P. EXIT   | 25.6                                      |                                  |                        | -106.9   | 4.36    |
| PUMP INLET  | 25.6                                      |                                  |                        | -106.9   | 4.36    |
| IST STAGE EXIT  | 25.6<br>272.9<br>272.9                    | 37.6<br>45.2<br>45.2             | 0.60                   | -80.9    | 4.21    |
| JBV INLET   | 272 9                                     | 45.2                             | 0.00                   | -80.9    | 4.21    |
| JBV EXIT  | 187.6                                     | 45.9                             | 0.00                   | -88.9    | 4.11    |
|   | 420.5                                     | 48.1                             | 0.60                   | -69.5    | 4.19    |
| 2ND STAGE EXIT<br>PUMP EXIT   | 563.0                                     | 50.8                             | 0.60                   | -58.6    | 4.17    |
| COOLANT EXIT  |   | 50.8                             | 0.60                   | -58.6    | 4.17    |
| COOLANT EXIT  | 561.0<br>347.0<br>333.5                   | 837.0                            |                        | 2855.1   | 0.08    |
| TBV INLET   | 333.5                                     | 837.0<br>837.1                   | 0.36                   | 2855-1   | 0.07    |
| TBV EXIT  | 217.1                                     | 837.9                            | 0.36                   | 2855.1   | 0.05    |
| LOX TRB INLET   | 333.5                                     | 837.1                            | 0.23                   | 2855.1   | 0.07    |
|   | 305.3                                     |                                  | 0.23                   | 2818.8   | 0.87    |
| H2 TRR IN FT  | 305.3                                     | 826.7                            | 0.23                   | 2818.0   | 0.07    |
| H2 TRR FXIT   | 224.8                                     | 792.0                            | 0.23                   | 2693.9   | 0.05    |
| H2 TRR DIFF   | 225 7                                     | 792.0                            |                        | 2693.9   | 0.85    |
| H2 RST TRR IN   | 222.R                                     | 792.0<br>792.0                   | 0.23                   | 2693.9   | 0.05    |
| LOX TRB EXIT H2 TRB INLET H2 TRB EXIT H2 TRB DIFF H2 BST TRB IN H2 BST TRB EXIT H2 BST TRB EXIT | 221.7                                     | 791.5                            | 0.23                   | 2692.2   | 0.05    |
| H2 BST TRR DIFF   | 221.5                                     | 791.5                            | 0.23                   | 2692.2   | 0.05    |
| H2 BST TRB DIFF O2 BST TRB IN O2 BST TRB EXIT O2 BST TRB DIFF H2 TANK PRESS GOV HEAT EXCH IN    | 220.6                                     | 791.5                            | 0.23                   | 2692.2   | 0.05    |
| O2 BST TRR EXIT   | 220.0                                     | 791.3                            | 0.23                   | 2691.4   | 0.05    |
| O2 BST TRR DIFF   | 220.6                                     | 791 3                            | 0.23<br>0.0006<br>0.60 | 2691.4   | 0.05    |
| H2 TANK PRESS<br>GOX HEAT EXCH IN   | 18.6                                      | 821.0                            | 0.0006                 | 2791.4   | 0.0043  |
| GOX HEAT EXCH IN  | 217.1                                     | 819.7                            | 0.60                   | 2791.4   | 0.05    |
| GOX HEAT EXCH OUT   | 2144                                      | 819.3                            | 0.60                   | 2798.8   | 0.05    |
| MIXER HOT IN  | 214 4                                     | 819.3                            | 0.60                   | 2790.8   | 0.05    |
| MIXER COLD IN   | 187.6                                     | 45.9                             | 0.00                   | -80.9    | 4.11    |
| MIXER COLD IN<br>MIXER OUT  | 187.6<br>187.6<br>187.6<br>180.5<br>178.0 |                                  | 0.60                   | 2790.0   | 0.04    |
| ESV INLET   | 187.6                                     | 819.5<br>819.5<br>819.6          | 0.60                   | 2798.0   | 0.84    |
| FSV INLET<br>FSV EXIT   | 180.5                                     | 819.6                            | 0.60<br>0.60           | 2798.8   | 0.04    |
| CHAMBER INJ   | 178.0                                     | 819.6                            | 0.60                   | 2798.8   | 0.04    |
| CHAMBER   | 158.2                                     |                                  |                        |          |         |
|   |   |                                  |                        |          |         |
|   | · DXY                                     | EN SYSTEM                        | CONDITIONS             |          |         |
| STATION   | PRESS                                     | TEMP                             | FLOM                   | ENTHALPY | DENSITY |
| B.P. INLET  | 16.0                                      | 162.7                            |                        |          | 71.17   |
| B.P. EXIT   | 25.5                                      | 162.7<br>162.8                   | 3.59<br>3.59<br>3.59   | 61.1     | 71.16   |
| PUMP INLET PUMP EXIT  | 25.5<br>25.5                              | 162.8                            | 3.59                   | 61.1     | 71.16   |
| PUMP EXIT   | 423.5                                     | 167.1                            | 3.59                   | 63.5     | 70.82   |
| OZ TANK PRESS<br>POSV INLET<br>POSV EXIT<br>OCV INLET<br>DCV EXIT                               | 16.0                                      | 400.0                            | 0.01                   | 204.8    | 0.12    |
| POSV INLET  | 423.2                                     | 167.1<br>167.9<br>167.1<br>168.0 | 2.68                   | bJ.5     | 70.82   |
| POSV EXIT   | 207.6                                     | 167.9                            | 2.68                   | 63.5     | 70.46   |
| OCV INLET   | 423.2                                     | 167.1                            | 0.90                   | 63.5     | 70.82   |
| OCV EXIT  | 158.3                                     | 168.0                            | 0.90                   | 63.5     | 70.38   |
| PRIMARY INJ   |   | 167.9                            | 2.68                   | 63.5     | 70.45   |
| SECONDARY INJ   | 158.3                                     | 0.8a1                            | 0.90                   | 63.5     | 70.38   |
| CHAMBER   | 158.2                                     |                                  |                        |          |         |
|   |   |                                  |                        |          |         |
|   |   | VE DATA                          |                        |          |         |
|   |   | ******                           |                        |          |         |
|   | DELTA P                                   |                                  | FLOW                   |          |         |
| J8V   | 85.                                       | 0.000                            | 0.00                   | D - 00   |         |
| TBV   | 116.                                      | 3.233                            | 0.36                   | 61.09    |         |
| FSV   | ٦.  | € 60.:                           | 0.60                   |          |         |
| POSV  | 216.                                      | 0.002                            | 2.68                   |          |         |
| OCV   | 265.                                      | 0.3:0                            | 0.90                   |          |         |
|   |   |                                  |                        |          |         |
|   |   | CTOR DATA                        |                        |          |         |
|   | ••••                                      | ********                         |                        |          |         |

|          | · FUEL * | •       | XID *  |
|----------|----------|---------|--------|
|          |          | PRIMARY | CECOND |
| CELP MAN | 2.68     | 49      | 0.02   |
| DELP INJ | 17.10    | -3.41   | 0.14   |
| AREA     | 1.14     | 1.08    | 0.43   |
| FLOW     | 0.60     | 2.68    | 0.90   |

TABLE 51. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 10% OF DESIGN THRUST LEVEL (CONTINUED)

|  | # TURBON  | ACHINERY I | PERFORMANCE DAT  | ΓA »               |                |             |
|--|-----------|------------|--|--------------------|----------------|-------------|
| *******  |           |            |  | <br>               |                |             |
| * H2 BOOST   | TIRRINE . |            |  | BOOST PL           |                |             |
| # H2 BOOST   | *******   |            |  | : BOOS! PI         |                |             |
| FEETCIENCY   | 0.44      | ,          | EFFICIE  |                    |                |             |
| HUDSEDUMED   | 0.44.     | •          | EFFICIE  | NCY                | 0.444          |             |
| SPEED (PPM)  | 10186     | •          | HORSEPO  | (RPM)              | 1.             |             |
| MEAN DIA (TM)  | 10175     |            | SPEED  | CRPMI              | 10195.         |             |
| FEE ADEA (THE)   | 1.50      | ,          | S SPEED  |                    | 1362.          |             |
| U/C (TREAL)  | 1.92      | •          | HEAD   | (FT)               | 228.           |             |
| MAY TID CREED  | 0.514     |            | DIA.   | (IN)               | 2.18           |             |
| STAGE  |           |            | TIP SPE  | (FT)<br>(IN)<br>ED | 97.            |             |
| EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES DELTA H (ACT)  | 1.        |            | VOL. FL<br>HEAD CO<br>FLOW CO  | OM                 | 61.<br>3.781   |             |
| GAMMA  | 1.41      |            | HEAD CO  | EF                 | 3.781          |             |
| PRESS RATIO (T/T   | 1.71      |            | FLOW CO  | E.F                | 0.092          |             |
| FRESS RATIO 1171   | , 1.01    |            |  |                    |                |             |
| ********   |           |            | _  |                    | _              |             |
| * H2 TURBINE   |           |            |  | ******             |                |             |
|  |           |            | •  | H2 PUMP            | -              |             |
| EFFICIENCY HORSEPOHER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | STAGE 1   | STAGE 2    |  | TAGE ONE           | T CTACE TIME   | STAGE THREE |
|  | ******    | *****      | 5  | MOE UNE            | STAGE THO      | STAGE THREE |
| EFFICIENCY   | 0.495     | 0.538      | FEETCIENCY   | 0.615              | 0 571          |             |
| HORSEPOWER   | 22.       | 19         | HODSEDONED   | 0.415              | 0.5/1          | 0.5//       |
| SPEED (RPM)  | 39541     | ₹9541      | SOEED (DOM)  | 70E/1              | 70541          | 7.          |
| MEAN DIA (IN)  | 3 47      | 3 47       | C CDEED  | 77341.             | 57541.         | 37541.      |
| FFF AREA (IN2)   | 0.71      | 0.26       | S SPEED  | 201.               | 527.           | 540.        |
| UZC (IDEAL)  | 0.231     | 0.258      | DIA (IN)   | 0363.              | 2061.          | 4710.       |
| MAX TIP SPEED  | 599       | 599        | TID COEED  | 3.67               | 5.02           | 3.02        |
| DELTA H  | 56.       | 58         | VOI FLOW   | 46                 | 341.           | 521.        |
| GAMMA (ACT)  | 1.41      | 1 41       | HEAD COEE  | 0 444              | 04.            | 4.          |
| PRESS RATIO(T/T  | 1.33      | 1.35       | FLOW COEF  | 0.044              | 0.600          | 0.582       |
|  |           |            | LON COLF   | 0.030              | 3.080          | 0.062       |
| **********   | ******    |            | ****   |                    |                |             |
| • 02 BOOST TI  | URBINE .  |            | * 02   | BOOST PUM          | (P 4           |             |
| ********   | *******   |            | ***  | ******             | ***            |             |
| EFFICIENCY HORSEPONER SPEED (RPM) MEAN DIA (IN) FFE ARFA (IN2)   | 0.435     |            | EFFICIEN<br>HORSEPOW   | ICY                | 3.437          |             |
| HORSEPOWER   | ٥.        |            | HORSEPOW   | ER                 | c.             |             |
| SPEED (RPM)  | 2633.     |            | SPEED  | (RPM)              | 2033.          |             |
| MEAN DIA (IN)  | 5.20      |            | S SPEED  |                    | 1361.          |             |
| EFF AREA (IN2)   | 2.02      |            | HEAD   | (FT)               | 19.            |             |
| U/C (IDEAL)  | 0.512     |            | DIA.   | (IN)               | 2.44           |             |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED<br>STAGES   | ьО.       |            | HORSEPOW<br>SPEED<br>S SPEED<br>HEAD<br>DIA.<br>TIP SPEE<br>VOL. FLO | D                  | 28.            |             |
| STAGES   | 1.        |            | VOL. FLO   | W                  | 23.            |             |
| DELTA H (ACT)  | 0.87      |            | VOL. FLO<br>HEAD COE<br>FLOW COE                                     | F                  | 3.790          |             |
| OAMINA   | 1.41      |            | FLOW COE   | F                  | 3.094          |             |
| PRESS RATIO (T/T)  | 1.01      |            |  |                    |                |             |
| **********   | _         |            |  |                    |                |             |
| . 02 TURBINE   | _         |            |  | ******             |                |             |
| *********  | _         |            |  | 2 PUMP *           |                |             |
| SEETCIENCY   | 0.614     |            |  | ****               |                |             |
| HORSEPOWER   | 12        |            | EFFICIENC<br>HORSEPOWE   | ~ Y                | 3.452          |             |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 26519     |            | COEED  | ER.                | 12.            |             |
| MEAN DIA (IN)  | 3 47      |            | SPEED<br>S SPEED   | CREMI              | 277            |             |
| EFF AREA (IN2)   | 0.25      |            | 3 SPEED  | (ET)               | 533.           |             |
| U/C (IDFAL)  | 0.212     |            | HEAD<br>DIA.   | (TN)               | 909.           |             |
| SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES  | 402       |            | TIP SPEEL  | (14)               | 90             |             |
| STAGES   | 1         |            |  |                    | 220.           |             |
| DELTA H (ACT)  | 37.16     |            | HEAD COSE  | •                  | . 677          |             |
| GAMMA  | 1.41      |            | HEAD COEF  |                    | 1.537<br>1.044 |             |
| PRESS RATIO (T/T)  |           |            | . COM COEF   |                    |                |             |
|  | •         |            |  |                    |                |             |

### TABLE 52. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 5% OF DESIGN THRUST LEVEL

| ENGINE | PERFORMANCE | PARAMETERS |
|--------|-------------|------------|
|        |             |            |

| CHAMBER PRESSURE          | 78.6   |
|---------------------------|--------|
| VAC ENGINE THRUST         | 1000.  |
| DEL. VAC. 1SP             | 478.5  |
| TOTAL ENGINE FLON RATE    | 2.1    |
| THROAT AREA               | 6.066  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.09   |
| CHAMBER/NOZZLE COOLANT DP | 96.    |
| CHAMBER/NOZZLE COOLANT DT | 891.   |
| ETA C.                    | 0.993  |
| CHAMBER (MD27) F 0        | 980.   |

|  |          | STATION C                               |  |  |                |
|--|----------|---|--|--|----------------|
|  | *******  | OWNER COM                               | DITIONS .  |  |                |
| STATION  | PRESS    | TEMP                                    | FLDM   | ENTHALPY<br>-107.5                             | DENSITY        |
| STATION B.P. INLET B.P. EXIT PUMP INLET IST STAGE EXIT JBV EXIT 2ND STAGE EXIT THE EXIT COOLANT INLET TBV INLET TBV INLET TBV EXIT LOX TRB INLET LOX TRB INLET LOX TRB EXIT H2 TRB EXIT H2 TRB EXIT H2 TRB DIFF H2 BST TRB EXIT H2 BST TRB CIFF H2 BST TRB CIFF H3 BST TRB CIFF H4 BST TRB CIFF H4 TANK PRESS GON HEAT EXCH IN TIMER HOT IN MINER COLD IN MINER OUT FSV EXIT CHAMBER INJ CHAMBER I | 18.6     | 37.4                                    | 0.30<br>0.30<br>0.30<br>0.20<br>0.00<br>0.30<br>0.30<br>0.30 |  | 4.37           |
| B.P. EXIT  | 21.3     | 37.5                                    | 0.30   | -107.2   | 4.36           |
| PUMP INLET   | 21.3     | 27.5                                    | 0.30   | -107.2   | 4.36           |
| IST STAGE EXIT   | 128.5    | 41.9                                    | 0.30   | -93.7  | 4.26           |
| JBV INLET  | 128.5    | 41.9                                    | 0.00   | -93.7  | 4.26           |
| JBV EXIT   | 95.2     | 42.1                                    | 0.00   | -93.7<br>-88.0                                 | 4.24           |
| 2ND STAGE EXIT   | 195.0    | 43.4                                    | 0.20   | -82.5  | 4.22           |
| PUMP EXIT  | 259.3    | 44.8                                    | 0.30   | -82.5  | 4.22           |
| COOLANT INLET  | 258.8    | 44.8                                    | 0.30   | 3197.0   | 0.83           |
| COOLANT EXIT   | 162.8    | 730.2                                   | 0.21   | ****   | 0.83           |
| TRY INCE   | 111.5    | 936.6                                   | 0.21   | 3197.0<br>3197.0<br>3197.0<br>3171.8<br>3171.8 | 0.02           |
| INV TOP INI ET   | 154.8    | 936.3                                   | 0.09   | 3197.0   | 0.03           |
| LOX TRB FXIT   | 144.0    | 929.1                                   | 0.09   | 3171.8   | 0.03           |
| H2 TRB INLET   | 144.0    | 929.1                                   | 0.09   | 3171.8   | 0.03           |
| H2 TRB EXIT  | 114.8    | 906.5                                   | 0.09   | 3092.6<br>3092.6<br>3092.6<br>3091.6           | 0.02           |
| H2 TRB DIFF  | 114.4    | 906.5                                   | 0.09   | 3092.6   | 0.02           |
| H2 BST TRB IN  | 114-1    | 906.5                                   | 0.09   | 3092.6   | 0.82           |
| H2 BST TRB EXIT  | 113.7    | 906.2                                   | 0.09   | 3071.6   | 0.02           |
| H2 BST TRB DIFF  | 113.6    | 906.2                                   | 0.09   | 3091.6<br>3091.6                               | 0.02           |
| O2 BST TRB IN  | 113.3    | 906.2                                   | 0.09   | 3091.1   | 0.02           |
| 02 BST TRB EXIT  | 113.1    | 906.1                                   | 0.09   | 7081 1   | 0.02           |
| 02 BST TRB DIFF  | 113.1    | 906.1                                   | 0.07<br>0.07   | 3163.9   | 0.0938         |
| H2 TANK PRESS  | 18.6     | 327.1                                   | 0.20   | 5165.9   | 0.02           |
| GOX HEAT EXCH IN   | 1 111.5  | 926.7                                   | 0.30   | 3162.5   | 0.82           |
| SIX HEAT EXCH OF   | 110.0    | 926.7                                   | 0.30   | 3162.5   | 0.02           |
| HIVER COLD IN  | 95.2     | 42.1                                    | 0.00   |  | 4.22           |
| MINER DUT  | 95.2     | 426.8                                   | 0.30   | -93.7<br>3162-5<br>3162.5                      | 0.82           |
| ESV INLET  | 95.2     | 926.8                                   | 0.30   | 3162.5   | 0.02           |
| FSV EXIT   | 91.2     | 926.8                                   | 0.30   | 3162.5<br>3162.5                               | 0.02           |
| CHAMBER INJ  | 8.8      | 926.8                                   | 0.30   | 3162.5   | 0.02           |
| CHAMBER  | 78.6     |   |  |  |                |
|  |          |   |  | ٠.   |                |
|  | POESS    | JEN STOLET                              | FLOW   | ENTHALPY<br>61.1                               | DENSITY        |
| STATION  | 14 O     | 162.7                                   | 1.79   | 61.1   | 71.17          |
| B.P. INLET<br>B.P. EXIT  | 19.6     | 152.7                                   | 1.79   | 61.1   |                |
| 9.P. EXIT PUMP INLET PUMP EXIT D2 TANK PRESS POSV INLET POSV EXIT CCV INLET  | 19.6     | 162.7<br>162.7<br>162.7<br>165.2        | 1.79   | 61.1   | 71.16          |
| PIMP FXIT  | 196.1    | 165.2                                   | 1.79<br>5.30   | 62.4   | 70.91          |
| 02 TANK PRESS  | 16.0     | -00.0                                   | 1.30   | 204.8  | 0.12           |
| POSY INLET   | 196.0    | 65.2                                    | 1.79   | 62.4   | 70.91          |
| POSV EXIT  | 100.4    | 105.0                                   | 1.79   | 52.4   | 70.75          |
| CCV INLET  | 196.0    | 165.2                                   | 0.00   | 62.4<br>62.4                                   | 70.91<br>70.72 |
| CV EXIT  | 78.6     | . 5 . 6                                 | 0.00   | 62.4   | 70.75          |
| PRIMARY INJ  | 96.4     | . 05.0                                  | 1.79   | 62.4   | 70.72          |
|  | 7B.6     | . 25 . 0                                | ,.00   | 32.7   |                |
| CHAMBER  | 78.6     |   |  |  |                |
|  |          | LVE DATA                                |  |  |                |
|  |          | ******                                  | E. 01:   | a DVDACC                                       |                |
| VALVE  | Dr.CTA P | AREA                                    | FLOW   | BYPASS<br>0.00                                 |                |
|  | 33.      | . 300                                   | 3.00   | 68.78  |                |
| 134  | 43.      | 1.315                                   | 0.30   | 00.70  |                |
| = 3 <b>V</b>   | -        | 272                                     | 1.79   |  |                |
| POSV   | ٠٠.      |   | 0.00   |  |                |
| ∂ <b>CV</b>  |          | .000<br>2.315<br>.653<br>1.032<br>2.000 | 3.55   |  |                |
|  | 1.2      | E TOR DATA                              | 7  |  |                |
|  |          |   |  |  |                |
| + FUE  |          | + 0x1                                   |  |  |                |
|  |          | : MARY                                  | 3.G0   |  |                |
| DELP MAN !   | .51      |   | 3.00   |  |                |
| DELP INJ 9   | . 73     |   | 0.45   |  |                |
| AREA 1   | . 14     | 3.5 <b>8</b>                            | 0.30   |  |                |
| ≓LOM 0   | .30      |   |  |  |                |
|  |          |   |  |  |                |

ORIGINAL PROS 15 OF POOR QUALITY

TABLE 52. — ADVANCED ENGINE PARAMETRIC STUDY SPLIT-EXPANDER ENGINE 5% OF DESIGN THRUST LEVEL (CONTINUED)

|  |                     |         | ERFORMANCE DATA                                    |            |                      |               |
|--|---------------------|---------|--|------------|----------------------|---------------|
|  |                     |         | ***********  | 4 8        |                      |               |
| ********   |                     |         |  | ******     | ***                  |               |
| * H2 BOOST T   |                     |         |  | BOOST PU   |                      |               |
| *******  |                     |         | ****   | *****      |                      |               |
| <b>EFFICIENCY</b>  | 0.314               |         | EFFICIEN<br>HORSEPOH                               | ICY        | 0.376                |               |
| HORSEPOHER   | 0.                  |         | HORSEPON   | ER         | 0.<br>6152.<br>1187. |               |
| SPEED (RPM)  | 6152.               |         | SPEED<br>S SPEED<br>HEAD<br>DIA.<br>TIP SPEE       | (RPM)      | 6152.                |               |
| MEAN DIA (IN)  |                     |         | S SPEED  |            | 1187.                |               |
| EFF AREA (IN2)   | 1.45                |         | HEAD   | (FT)       | 88.                  |               |
| U/C (IDEAL)  |                     |         | DIA.   | (IN)       | 2.18                 |               |
| MAX TIP SPEED  |                     |         | TIP SPEE   | D          | 58.<br>31.           |               |
| STAGES   | 1.                  |         | VOL. FLO   | )M         | 0.828                |               |
| DELTA H (ACT)  | 0.97                |         | HEAD COE   | r          | 0.076                |               |
| GAMMA  | 1.43                |         | HEAD COE   | ·r         | 0.070                |               |
| PRESS RATIO (T/T   | ) 1.01              |         |  |            |                      |               |
| *********  |                     |         | 4.4  | ******     | •                    |               |
| * H2 TURBINE   |                     |         | •  | H2 PUMP    | •                    |               |
|  |                     |         | **   | ******     | =                    |               |
|  | STAGE L             | STAGE 2 | 51   | AGE ONE    | STAGE THO            | STAGE THREE   |
|  | *****               | *****   | 41   | *****      | *******              | ******        |
| EFFICIENCY HORSEPOWER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 0.370               | 0.417   | EFF ICIENCY  | 0.340      | 0.508                | 0.515         |
| HORSEPOMER   | 6.                  | 5.      | HORSEPOWER   | 6.         | 2.                   | 2.            |
| SPEED (RPM)  | 25943.              | 25943.  | SPEED (RPM)  | 25943.     | 25943.               | 25793.<br>487 |
| MEAN DIA (IN)  | 3.47                | 3.47    | S SPEED  | 314.       | 2257                 | 2190          |
| EFF AREA (IN2)   | 0.21                | 0.26    | HEAD (F1)  | 337U.      | 3 02                 | 3.02          |
| U/C (IDEAL)  | 0.163               | 0.188   | DIA. (IN)  | 419        | 342                  | 342.          |
| MAX TIP SPEED  | 393.                | 393.    | TIP SPEED  | 31.        | 32.                  | 32.           |
| DELTA H  | 43.                 | 1 43    | HEAD COFF  | 0.662      | 0.621                | 0.603         |
| GAMMA (AUT)  | 1.43                | 1.45    | FILON COEF   | 0.023      | 0.046                | 0.046         |
| PRESS RATIONINI  | 1.33                | 1.55    |  |            |                      |               |
| ********   |                     |         | ****   | *******    | * # # #              |               |
| * 02 BOOST 1   | TURBINE .           |         |  | BOOST PU   |                      |               |
| ********   | ********            |         |  | *******    |                      |               |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)<br>MEAN DIA (IN)   | 0.307               |         | EFFICIEN HORSEPON SPEED S SPEED HEAD DIA. TIP SPEE | NCY        | 0.369                |               |
| HORSEPOWER   | 0.                  |         | HORSEPO  | HER        | U.                   |               |
| SPEED (RPM)  | 1579.               |         | SPEED  | (RPH)      | 1199                 |               |
| MEAN DIA (IN)  | 5.20<br>2.02        |         | 2 2PEED  | (ET)       | 7                    |               |
| EFF AREA (IN2)   | 2.02                |         | DIA  | (IN)       | 2.44                 |               |
| U/C (IDEAL) MAX TIP SPEED  | 0.512<br>36.        |         | TIP SPE  | FN         | 17.                  |               |
| MAX TIP SPEED  | J <b>O</b> .        |         | VOL. FL  | OM.        | 11.                  |               |
| DELTA H (ACT)  | 0.49                |         | HEAD COL   | EF         | 0.839                |               |
| STAGES<br>DELTA H (ACT)<br>GAMMA   | 1.43                |         | HEAD COL<br>FLOW COL                               | EF         | 0.078                |               |
| PRESS RATIO (T/  | 7) 1.01             |         |  |            |                      |               |
|  |                     |         |  |            |                      |               |
| ********   |                     |         |  | ******     |                      |               |
| # 02 TURBINE   |                     |         |  | 02 PUMP *  |                      |               |
| ********   | ***                 |         |  |            |                      |               |
| EFFICIENCY<br>HORSEPOWER   | 0.3 <b>83</b><br>3. |         | EFFICIE<br>HORSEPO                                 | WFR        | 3.                   |               |
| HORSEPOWER  SPEED (RPM)  | 1747E               |         | SPEED  | (RPM)      | 17635.               |               |
|  | 7 (7                |         | S SPEED  |            | 721.                 |               |
| HEAN DIA (IN)  | 0.75                |         | HEAD   | (FT)       | 158.                 |               |
| U/C TIDEALL  | 0.147               |         | DIA.   | (IN)       | 1.90                 |               |
| MAY TIP SPEED  | 267.                |         | TIP SPE  | (IN)<br>ED | 147.                 |               |
| MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES  | 1.                  |         | VOI F  | ∩W         | 11.                  |               |
| DELTA H (ACT)  | 25.18               |         | HEAD CC  | EF         | 0.537                |               |
| OHIUM  |                     |         | FLOW CO  | EF         | 0.033                |               |
| PRESS RATIO (T/  | T) 1 07             |         |  |            |                      |               |

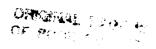


TABLE 53. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 100% OF DESIGN THRUST LEVEL

## ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1763.9 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 20008. |
| DEL. VAC. ISP             | 480.8  |
| TOTAL ENGINE FLON RATE    | 41.7   |
| THROAT AREA               | 5.547  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.00   |
| CHAMBER/NOZZLE COOLANT DP | 874.   |
| CHAMBER/NOZZLE COOLANT DT | 503.   |
| ETA C#                    | 0.995  |
| CHAMBED (NO.77) E. O.     | 11788  |

| Ch.  |                          | E UMLAN   | ı Di                                  | 503.   |         |
|--|--------------------------|-----------|---------------------------------------|--|---------|
|  | A C.<br>■<br>AMBER/NOZZL | F 0       |                                       | 0.993<br>1139 <b>0.</b>  |         |
| Ch.  | APRIDE N / HUZ Z L       | .E. W     |                                       | 11370.   |         |
|  | ENGIN                    | E STATIO  | N CONDITIONS                          |  |         |
|  |                          |           | ********                              |  |         |
|  | * FUEL                   | SYSTEM    | CONDITIONS .                          |  |         |
| STATION  | PRESS                    | TEMP      | FLOH                                  | ENTHALPY   | DENSITY |
| STATION B.P. INLET B.P. EXIT PUMP INLET  | 18.6                     | 37.4      | 5.96                                  | -107.5<br>-103.0   | 4.37    |
| B.P. EXIT  | 100.2                    | 38.5      | 5.96                                  | -103-0   | 4.39    |
| PUMP INLET   | 100.2                    | 38.5      | 5.96                                  | -103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-103.0<br>-1 | 4.39    |
| IST STAGE EXIT   | 1877.6                   | 63.7      | 5.96                                  | 8.5  | 4.42    |
| 2ND STAGE EXIT   | 3643.0                   | 87.7      | 5.96                                  | 118.3  | 4.47    |
| PUMP EXIT  | 5403.2                   | 110.6     | 5.96                                  | 226.1  | 4.54    |
| COLD REGEN IN  | 5349.1                   | 111.1     | 5.96                                  | 226.1  | 4.52    |
| COLD REGEN EX  | 5295.6                   | 255.4     | 5.96                                  | 757.5  | 2.73    |
| COOLANT INLET  | 5295.6                   | 255.4     | 5.96                                  | 757.5  | 2.73    |
| COOLANT EXIT   | 4421.6                   | 758.6     | 5.96                                  | 2668.9   | 0.96    |
| TBV INLET  | 4377.3                   | 758.9     | 0.31                                  | 2668.9   | 0.95    |
| IRA EXII   | 2035.2                   | 7/3.8     | 0.31                                  | 2668.9   | 0.47    |
| LOX TRB INCE!  | 43/7.3                   | 758.9     | 5.65                                  | 2668.9   | 0.95    |
| COX INB EXIT   | 39/8.6                   | 744.7     | 5.65                                  | 2608.7   | 0.89    |
| H2 TRB INLET   | 39/8.6                   | 744.7     | 5.65                                  | 2608.9   | 0.89    |
| HE INB CALL  | 2162.4                   | 657.7     | 5.65                                  | 2261.7   | 0.58    |
| H2 IKB DIFF  | 2131.1                   | 657.8     | 5.65                                  | 2261.7   | 0.57    |
| H2 BSI IRB IN  | 2109.8                   | 658.0     | 5.65                                  | 2261.7   | 0.56    |
| HE BOT TOR DIES  | 2090.5                   | /5/ 0     | 5.65                                  | 2257.0   | 0.56    |
| M2 851 IRB UIFF  | 2077.0                   | 656.8     | 5.65                                  | 2257.0   | 0.56    |
| 02 BST TRB IN  | 2056.3                   | 656.9     | 5.65                                  | 2257.0   | 0.55    |
| 02 BS1 TRB EATT  | 2046.9                   | 656.2     | 5.65                                  | 2254.4   | 0.55    |
| OF BPI IND DILL  | 2045.4                   | 656.3     | 5.65                                  | 2254.4   | 0.55    |
| THE TANK PRESS   | 2075 2                   | 8/3.5     | 0.00/1                                | 2275.8   | J.0052  |
| CON HEAT ENCH OF   | T 2024 A                 | 4/2.0     | 5.65                                  | 2273.8   | 0.54    |
| YOT DECEN IN   | 2026.0                   | 662.U     | 5.65                                  | 2274.4   | 0.54    |
| TOT REGEN IN   | 1045.0                   | 502.0     | 5.95                                  | 22/4.4   | 0.54    |
| HUT KEGEN EX   | 1965.4                   | 507.3     | 5.05                                  | 1714.0   | 0.67    |
| ESA INCEI  | 1965.4                   | 520.9     | 5.75                                  | 1763.4   | J. 66   |
| FSV EXIL   | 1916.2                   | 521.1     | 5.95                                  | 1763.4   | 0.64    |
| CHAMBER INJ  | 1897.1                   | 521.2     | 5.95                                  | 1765.4   | 0.63    |
| CHARDEN  | 1763.5                   |           |                                       |  |         |
| STATION B.P. INLET B.P. EXIT PUMP INLET IST STAGE EXIT COLD STAGE EXIT COLD REGEM IN COLD REGEM EX COOLANT INLET TBV EXIT LOX TRB INLET LOX TRB EXIT H2 TRB INLET H2 TRB DIFF H2 BST TRB IN H2 BST TRB ENI H2 BST TRB ENI H2 BST TRB ENI H2 BST TRB IN H0 BST TRB ENI H2 TANN PRESS GOX HEAT EXCH IN GOX HEAT EXCH IN HOT REGEN IN HO | * UXVC                   | EN SYSTE  | M COMPLETONS                          | -  |         |
| STATION  | PRESS                    | TEMP      | FLOW                                  | FNTHM PV   | CENSITY |
| B.P. INIFT   | 16.0                     | 162.7     | 75 77                                 | 61 1   | 71 17   |
| S.P. EXIT  | 134.9                    | 163.3     | 25.77                                 | 61.5   | 71.20   |
| PUMP INLET   | 134.9                    | 163.3     | 35-77                                 | 61.5   | 71.20   |
| PUMP EXIT  | 2852.9                   | 176.1     | 25.77                                 | 70.9   | 71.70   |
| 02 TANK PRESS  | 16.0                     | 400.0     | 0.06                                  | 204.8  | 9.12    |
| POSV INLET   | 2824.3                   | 176.2     | 8.55                                  | 70.9   | 71.05   |
| POSV EXIT  | 2209.8                   | 178.2     | 8.55                                  | 70.9   | 70.86   |
| CCV INLET  | 2824.3                   | 176.2     | 27.16                                 | 70.9   | 71.65   |
| SCV EXIT   | 1936.8                   | 179.6     | 27.16                                 | 70.9   | 70.27   |
| PRIMARY INJ  | 2210.2                   | 178.5     | 8.55                                  | 70.9   | 70.70   |
| SECONDARY INJ  | 1905.3                   | 179.7     | 27.16                                 | 70.9   | 70.22   |
| CHAMBER  | 1763.8                   |           |                                       |  |         |
|  |                          |           |                                       |  |         |
|  | VAL                      | WE DATA   |                                       |  |         |
|  | 444                      | *****     |                                       |  |         |
| VALVE  | DELTA P                  | 4REA      | FLOH                                  | T BYPASS   |         |
| 73 <b>V</b>  | 2342.                    | 3.014     | 0.31                                  | 5.17   |         |
| ⊂S <b>V</b>  | 49.                      | 1.528     | 5.95                                  |  |         |
| POSV   | 515.                     | 7.067     | 8.55                                  |  |         |
| CCV  | 387.                     | 3.161     | FLOM<br>0.31<br>5.95<br>9.55<br>27.16 |  |         |
|  |                          |           |                                       |  |         |
|  |                          | CTCR DATA |                                       |  |         |
|  |                          |           |                                       |  |         |
| • FUEL   | •                        | • 0x1     | D 4                                   |  |         |
| DELP MAN (9.9)   | ₽ŖI                      | MARY      | SECOND                                |  |         |
| DELP MAN 19.9  | 13 49                    | .57       | 15.71                                 |  |         |
| DELP INJ 113.2   | 9 -46                    | . 3 3     | 141.36                                |  |         |

|              | · FUEL ·    |         | OXID ◀ |  |
|--------------|-------------|---------|--------|--|
|              |             | PRIMARY | SECOND |  |
| CELP MAN     | ; 9 . 93    | 49.57   | 15.71  |  |
| CELP INJ     | 113.20      | 446.33  | 141.36 |  |
| ≟R <b>EA</b> | 1.05        | 3.27    | 0.41   |  |
| FLOW         | 5 <b>95</b> | 8 55    | 27.16  |  |

TABLE 53. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 100% OF DESIGN THRUST LEVEL (CONTINUED)

|  |              | (0011    | III(CDD)       |              |                                |               |
|--|--------------|----------|----------------|--------------|--------------------------------|---------------|
|  | ********     |          | **********     | ***          |                                |               |
|  | * TURBONAC   | HINERY P | ERFORMANCE DAT | A =          |                                |               |
|  | ********     | ******   | ********       | 4 # M        |                                |               |
| ********   | ********     |          | ****           |              |                                |               |
| * H2 BOOST   | TURBINE .    |          | ■ H2           | BOOST PU     | MP #                           |               |
| ********   | *******      |          |                | ******       | ***                            |               |
| <b>EFFICIENCY</b>  | 0.797        |          | EFFICIE        | NCY          | 0.766                          |               |
| HORSEPOMER   | 38.          |          | HORSEPO        | WER          | 38.                            |               |
| SPEED (RPM)  | 45998.       |          | SPEED          | (RPM)        | 45998.                         |               |
| MEAN DIA (IN)  | 1.30         |          | S SPEED        |              | 3047.                          |               |
| EFF AREA (IN2)   |              |          | HEAD           | (FT)<br>(IN) | 2682.                          |               |
| U/C (IDEAL)  | 0.478        |          |                |              | 2.18                           |               |
| MAX TIP SPEED  | 260.         |          | TIP SPE        |              | 437.                           |               |
| STAGES   | 1.           |          | VOL. FL        |              | 609.                           |               |
| DELTA H (ACT)  |              |          | HEAD CO        |              | 0.451                          |               |
| GAMMA  | 1.35         |          | FLOW CO        | EF           | 0.201                          |               |
| PRESS RATIO (T/)   | T) 1.01      |          |                |              |                                |               |
|  |              |          |                |              |                                |               |
| ********   |              |          |                | *******      |                                |               |
| # H2 TURBINE   |              |          |                | H2 PUMP      |                                |               |
| *******  |              |          |                | ********     |                                |               |
|  | STAGE 1      |          |                |              |                                | STAGE THREE   |
|  |              | ******   | **             | ******       | *******                        | *********     |
| EFFICIENCY   | 0.841        | 0.828    | EFFICIENCY     | 0.668        | 0.669                          | 0.670         |
| HURSEPUWER   | 1388.        | 1587.    | HORSEPOMER     | 941.         | 925.                           | 909.          |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)<br>MEAN DIA (IN)     | 129711. 1    | 24711.   | SAFFO (KSW)    | 124911.      | 129911.                        | 126911.       |
| MEAN DIA (IN)  | 2.78         | 2.78     | 2 SPEED        | 922.         | 826.                           | 831.          |
| EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) | 0.31         | 0.40     | DIA (TH)       | 280.8.       | 3.43                           | 56217.        |
| MAY TID CREED  | 1515         | 1616     | TID COCED      | 1040         | 3.43<br>1869.<br>599.<br>0.527 | 3.43<br>1868. |
| DELTA H  | 174          | 177      | NUM ELUM       | 1007.        | 1867.<br>E 0 0                 | 589.          |
| CAMMA (ACT)  | 1 36         | 1 75     | WEAT COEE      | 003.         | 0 527                          | 0.518         |
| PRESS RATIO(T/T  | 1.34         | 1.33     | FLOW COEF      | 0.099        | 0.099                          | 0.099         |
| FRESS RATIONIN   | 1.34         | 1.37     | TON COEF       | 0.077        | 0.077                          | 0.077         |
| ********   | ******       |          | ****           | ******       | ***                            |               |
| * 02 BOOST T   | URBINE .     |          |                | BOOST PUM    |                                |               |
| *******  |              |          |                | *****        |                                |               |
| EFFICIENCY   | 0.863        |          | EFFICIEN       | ICY          | 0.764                          |               |
| HORSEPOWER   | 20.          |          | HORSEPON       |              | 20.                            |               |
| SPEED (RPM)  |              |          | SPEED          |              | 12315.                         |               |
| MEAN DIA (IN)  | 3.68         |          | S SPEED        |              | 2028.                          |               |
| EFF AREA (IN2)   | 3.00         |          | HEAD           | (FT)         | 241.                           |               |
| U/C [[DEAL]  | 0.514        |          | DIA.           | (IN)         | 2.44                           |               |
| MAX TIP SPEED  | 198.         |          | TIP SPEE       | ם            | 131.                           |               |
| STAGES   | 1.           |          | VOL. FLO       | H            | 226.                           |               |
| DELTA H (ACT)  | 2.56         |          | HEAD COE       | F            | 0.450                          |               |
| GAMMA  | 1.35         |          | FLOW COE       | F            | 0.201                          |               |
| PRESS RATIO (T/T   | 1.00         |          |                |              |                                |               |
|  |              |          |                |              |                                |               |
| *********  |              |          | ***            | ******       |                                |               |
| * OZ TURBINE   | •            |          |                | 2 PUMP *     |                                |               |
| *********  |              |          |                | *******      |                                |               |
| EFFICIENCY   | 0.852        |          | EFFICIEN       |              | 0.739                          |               |
| HORSEPOWER   | 480.         |          | HORSEPOW       |              | 480.                           |               |
| SPEED (RPM)  | 76933.       |          | SPEED          |              | 76933.                         |               |
| MEAN DIA (IN)  |              |          | S SPEED        |              | 1813.                          |               |
| EFF AREA (IN2)   |              |          | HEAD<br>Dia.   | (FT)         | 5457.                          |               |
| U/C (IDEAL)  | 0.496        |          |                |              | 1.92                           |               |
| MAX TIP SPEED<br>STAGES                                      | 933.         |          | TIP SPEE       |              | 644.                           |               |
|  | 1.           |          | VOL. FLO       |              | 224.<br>0.423                  |               |
| CELTA H (ACT)  |              |          | HEAD COE       |              |                                |               |
| PRESS RATIO (T/T   | 1.25<br>1.10 |          | FLOW COE       | F            | 0.154                          |               |
| PRESS RATIO CIVI   | 1.15         |          |                |              |                                |               |
|  |              |          |                |              |                                |               |
|  |              |          |                |              |                                |               |
| 25   | EGENERATOR   | DATA     |                |              |                                |               |
|  | ****         |          |                |              |                                |               |
|  | IDE HOT      |          |                |              |                                |               |
|  |              | 50.61    |                |              |                                |               |
|  |              | 54.70    |                |              |                                |               |
|  |              | 1.46     |                |              |                                |               |
|  | . 96         | 5.05     |                |              |                                |               |
| EFFECTIVENESS  | 0.28         |          |                |              |                                |               |
| NTU  | 0.40         |          |                |              |                                |               |
| CRATIO   | 0.43         |          |                |              |                                |               |
| CMIN   | 20.47        |          |                |              |                                |               |
| REGEN Q  | 3166.75      |          |                |              |                                |               |
|  | · · ·        |          |                |              |                                |               |

TABLE 54. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 50% OF DESIGN THRUST LEVEL

|   |                                      |                         | E PARAMETER    |                                   |                 |  |
|---|--------------------------------------|-------------------------|----------------|-----------------------------------|-----------------|--|
|   | ER PRESSU                            |                         |                | 877.5                             |                 |  |
|   | NGINE THE                            |                         |                | 100 <b>00.</b><br>47 <b>9.8</b>   |                 |  |
|   |                                      | LOH RATE                |                | 20.8                              |                 |  |
| THROA   | T AREA                               |                         |                | 5 . 547                           |                 |  |
|   | E AREA RA                            |                         |                | 100 <b>0.0</b><br>6. <b>08</b>    |                 |  |
|   | E MIXTURE<br>Er/NO22LE               | COOLANT                 | DP             | 703.                              |                 |  |
|   |                                      | COOLANT                 |                | 590.                              |                 |  |
| ETA C   | ;#<br>Ber/Nozzle                     | . 0                     |                | 0.9 <b>93</b><br>652 <b>0</b> -   |                 |  |
|   | ENGINE                               | STATION                 | CONDITIONS     |                                   |                 |  |
| •   | * FUEL                               | SYSTEM CO               | MDITIONS *     |                                   |                 |  |
| STATION   |                                      | TEMP                    | FLOW           | ENTHALPY                          | DENSIT<br>4.37  |  |
| B.P. INLET<br>B.P. EXIT   | 18.6<br>52.5                         | 37.4<br>37.9            | 2.98<br>2.98   | -107.5<br>-105.6                  | 4.38            |  |
|   |                                      | 37.9                    | 2.98           | -105.6                            | 4.28            |  |
| 1ST STAGE EXIT  | 52.5<br>896.4                        | 51.0                    | 2.98           | -50.2                             | 4.36            |  |
| PUMP INLET 1ST STAGE EXIT 2ND STAGE EXIT PUMP EXIT                            | 1724.1                               | 63.4<br>75.3            | 2.98<br>2.98   | 3.9<br>56.7                       | 4.36<br>4.37    |  |
| PUMP EXIT<br>COLD REGEN IN  | 2535.4                               | 75.3<br>75.4            | 2.98           | 56.7                              | 4.36            |  |
| COLD REGEN EX   | 2502.1                               | 262 1                   | 2.98           | 751.9                             | 1.55            |  |
| COOLANT INLET   | 2502.1                               | 262.1                   | 2.98           | 751.9                             | 1.55            |  |
| COOLANT EXIT  | 1799.1<br>1770.9                     | 821.6                   | 2.9B<br>0.94   | 2939.4<br>2939.4                  | 0.30<br>0.37    |  |
|   | 1018.3                               | 851.8<br>856.6          | 0.94           | 2939.4                            | 8.22            |  |
| OV TOO THEFT  | 1770 9                               | 251 2                   | 2.04           | 2939.4                            | 0.37            |  |
| LOX TRB EXIT  | 1628.9<br>1628.9<br>1057.4<br>1047.6 | 839.0                   | 2.04           | 28 <b>90.7</b><br>289 <b>0.7</b>  | 0.35<br>0.35    |  |
| H2 TRB IMLET<br>H2 TRB EXIT   | 1628.9                               | 839.0<br>775.5          | 2.04           | 2654.1                            | 0.25            |  |
| H2 TRB DIFF   | 1047.6                               | 775.5<br>775.6<br>775.6 | 2.04           | 2654-1                            | 0.25            |  |
|   |                                      | 773.0                   |                | 2654.1                            | 0.24            |  |
| H2 BST TRB EXIT   | 1035.1                               | 774.8                   | 2.04           | 2651.2<br>2651.2                  | 0.24<br>0.24    |  |
| H2 BST TRB DIFF   | 1030.9                               | 774.9<br>774.9          | 2.04           | 2651.2                            | 0.24            |  |
| H2 BST TRB EXIT H2 BST TRB DIFF O2 BST TRB IN O2 BST TRB EXIT C2 BST TRB DIFF | 1021.8                               | 774.9<br>774.5          | 2.04           | 2649.7                            | 0.24            |  |
| 02 BST TRB DIFF   | 1021.4                               | 774.5                   | 2.04           | 2649-7                            | 0.24            |  |
| H2 TANK PRESS   | 18.6                                 | 806.6<br>800.3          | 0.0030<br>2.04 | 27 <b>40.7</b><br>27 <b>40.</b> 7 | 0.0 <b>844</b>  |  |
| GOX HEAT EXCH IN  |                                      | 799.8                   | 2.04           | 2738.7                            | 0.23            |  |
| HOT REGEN IN  |                                      | 799.8                   | 2.04           | 2728.7                            | 0.23            |  |
| HOT REGEN EX  | 996.7                                | 514.2                   | 2.04           | 1724.9<br>2106.5                  | 0.25            |  |
| FSV INLET<br>FSV EXIT   | 996.7<br>967.6                       | 620.3<br>620.4          | 2.98<br>2.98   | 2106.5                            | 0.28            |  |
| CHAMBER INJ   | 956.8<br>877.4                       | 620.5                   | 2.98           | 2106.5                            | 0.28            |  |
| CHARDER   |                                      | ÆN SYSTEM               | CONDITIONS     | s •                               |                 |  |
| STATION   | PRESS                                | TEMP                    | FLOW           | ENTH <b>ALPY</b><br>61.1          | DEMS17<br>71.17 |  |
| B.P. INLET<br>B.P. EXIT   | 16.0<br>64.7<br>64.7                 | 162.7<br>163.0          | 17.90<br>17.90 | 61.2                              | 71.18           |  |
| PUMP INLET  | 64.7                                 | 163.0<br>170.8          | 17.90          | 61.2                              | 71.18           |  |
|   | 1571.5                               |                         |                | 66.8                              | 71.35           |  |
| 02 TANK PRESS   | 16.0<br>1564.3                       | 400.0<br>170.9          | 0.03<br>6.87   | 204.8                             | 0.12<br>71.24   |  |
|   | 1230.4                               | 172.1                   | 6.87           | 66.8                              | 70.80           |  |
|   | 1564.3                               | 170.9                   | 11.30          | b6.8                              | 71.54           |  |
| OCV EXIT  | 905.8                                | 173.3<br>172.3          | 11.30<br>5.87  | 66.8<br>66.8                      | 70.27<br>70.70  |  |
| PRIMARY INJ<br>SECONDARY INJ  | 900.7                                | 173.3                   | 11.30          | 56.8                              | 70.26           |  |
| CHAMBER   | 877.6                                |                         |                |                                   |                 |  |
|   |                                      | VE DATA                 |                |                                   |                 |  |
| VALVE   | DELTA P                              | REA                     | FLOW           | Y BYPASS                          |                 |  |
| TBV   | 753.<br>39.                          |                         | 0.94           | 31.42                             |                 |  |
| FSV<br>POSV   | 334.                                 | 1.367                   | 0.87           |                                   |                 |  |
| OC.A.   | o59.                                 |                         | 11.00          |                                   |                 |  |
|   |                                      | CTOR DATA               |                |                                   |                 |  |
| ◆ FUEL  | PR:                                  |                         | SECOND         |                                   |                 |  |
| DELP MAN 11.25  |                                      | 2.04                    | 2.57           |                                   |                 |  |
| DELP INJ -8.07  |                                      | 3.4.                    | 0.41           |                                   |                 |  |
|   |                                      |                         | 11.00          |                                   |                 |  |

TABLE 54. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 50% OF DESIGN THRUST LEVEL (CONTINUED)

|  | * TURBONA              | ACHINERY P | ERFORMANCE DATA                  | A #        |                        |             |  |
|--|------------------------|------------|----------------------------------|------------|------------------------|-------------|--|
|  |                        |            | ******                           |            |                        |             |  |
| *************  |                        |            |                                  |            |                        |             |  |
| R H2 BOOST TURBINE P   |                        |            |                                  | BOOST PU   |                        |             |  |
|  |                        |            |                                  | ********   |                        |             |  |
| EFFICIENCY<br>HORSEPOHER   | 0.548                  | •          | EFFICIEN<br>HORSEPON             | VLY<br>JED | 0.729                  |             |  |
| HORSEPOHER<br>SPEED (RPM)  | 77091                  |            | SPEED                            | (DDM)      | 8.<br>27083.           |             |  |
| MEAN DIA (IN)  | 1.30                   | 1          | S SPEED                          |            | 2454                   |             |  |
| FEE AREA (IN2)   | 2.49                   |            | HFAD                             | (FT)       | 1115.                  |             |  |
| U/C (IDEAL)  | 0.478                  | 1          | HEAD<br>DIA.                     | (IN)       | 2.18                   |             |  |
| EFF AREA (1N2)<br>U/C (1DEAL)<br>MAX TIP SPEED   | 153.                   |            | TIP SPEE                         | D          | 257.                   |             |  |
| STAGES   | 1.                     |            | VOL. FLO                         | )W         | 306.                   |             |  |
| DELTA H (ACT)  | 2.87                   |            | VOL. FLO<br>HEAD COS<br>FLOM COS | F          | 0.541                  |             |  |
| GAMMA  | 1.45                   |            | FLOW COS                         | F          | 0.172                  |             |  |
| PRESS RATIO (T/)   | 1.01                   |            |                                  |            |                        |             |  |
| **********   |                        |            |                                  |            |                        |             |  |
|  |                        |            |                                  | *******    |                        |             |  |
| * H2 TURBINE   |                        |            |                                  | H2 PUMP    |                        |             |  |
|  | STAGE 1                | STAGE 2    | SI                               |            |                        | STAGE THREE |  |
|  |                        |            | **                               |            |                        |             |  |
| EFFICIENCY HORSEPOMER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 0.690                  | 0.713      | EFFICIENCY                       | 0.646      | 0.649                  | 0.652       |  |
| HORSEPOWER   | 363.                   | 321.       | HORSEPOWER                       | 233.       | 228.                   | 222.        |  |
| SPEED (RPM)  | 81622.                 | 81622.     | SPEED (RPM)                      | 81622.     | 81622.                 | 81622.      |  |
| MEAN DIA (IN)  | 2.78                   | 2.78       | S SPEED                          | 663.       | 673.                   | 683.        |  |
| EFF AREA (IN2)   | 0.31                   | 0.40       | HEAD (FT)                        | 27819.     | 27316.                 | 26753.      |  |
| U/C (IDEAL)  | 0.328                  | 0.354      | DIA. (IN)                        | 3.43       | 3.43                   | 3.43        |  |
| MAX TIP SPEED  | 990.                   | 990.       | TIP SPEED                        | 1221.      | 1221.                  | 1221.       |  |
| DELTA H  | 125.                   | 111.       | VOL. FLOW                        | 307.       | 307.                   | 306.        |  |
| DOESS DATIONT  | 1.45                   | 1.45       | HEAD CUEF                        | 0.600      | 0.589                  | 0.578       |  |
| PRESS MALIDELY   | 1.54                   | 1.37       | FLUM COEF                        | 0.076      | 0.078                  | 0.079       |  |
| ********   | *******                |            | ****                             | *****      | ***                    |             |  |
| • OR ROOST T   | IDDINE .               |            | * 02                             | BOOST PUR  | 1P *                   |             |  |
| ******   | ******                 |            |                                  | ******     |                        |             |  |
| EFFICIENCY<br>HORSEPOWER   | 0.701                  |            | EFFICIEN<br>HORSEPOW             | CY         | 0.729                  |             |  |
| HORSEPOWER   | 4.                     |            | HORSEPOW                         | ER         | 4.                     |             |  |
| HORSEPOHER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED  | 7188.                  |            | SPEED                            | (RPM)      | 118 <b>8.</b><br>2942. |             |  |
| MEAN DIA (IN)  | 3.68                   |            | S SPEED                          |            | 2.42.                  |             |  |
| EFF AREA CINET   | 3.60                   |            | HEAD<br>DIA.                     | (11)       | 2.44                   |             |  |
| MAX TIP SPEED  | 115.                   |            | TIP SPEE                         | י וווי     | 77.                    |             |  |
| STAGES   | 1.                     |            | VOI FLO                          | u          | 117                    |             |  |
| DELTA H (ACT)  | 1.52                   |            | HEAD COE                         | F          | 0.542                  |             |  |
| DARIMA   | 1.43                   |            | HEAD COE<br>FLOW COE             | F          | 2.172                  |             |  |
| PRESS RATIO (T/T   | 1.00                   |            |                                  |            |                        |             |  |
|  |                        |            |                                  |            |                        |             |  |
| *********  |                        |            |                                  | ******     |                        |             |  |
| * 02 TURBINE   |                        |            |                                  | 2 PUMP 4   |                        |             |  |
| ************   | 0.704                  |            |                                  | *******    | 2 202                  |             |  |
| HORSEPOWER   | 161                    |            | EFFICIEN<br>HORSEPOW             | F D        | 141                    |             |  |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 53400.                 |            | SPEED                            | (RPM)      | 53400.                 |             |  |
| MEAN DIA (IN)  | 2.78                   |            | C COEED                          |            | 170/                   |             |  |
| MEAN DIA (IN) FFF AREA (IN2) J/C (IDEAL)   | 0.43                   |            | S SPEED<br>SEAD<br>SEA.          | (FT)       | 3041.                  |             |  |
| JZC (IDEAL)  | 0.348                  |            | DIA.                             | (IN)       | 1.92                   |             |  |
| AK III SICES   | 54 <b>8.</b><br>1.     |            | TIP SPEE                         | ט          | 447.                   |             |  |
| STAGES   | 1 -                    |            | VCL. FLO                         | 4          | 113.                   |             |  |
| DELTA H (ACT)  | 48.72                  |            | HEAD COEF                        | -          | 3.490                  |             |  |
| - BAMMA<br>- PRESS RATIO (T/T  | ; . 45                 |            | FEOM COE                         | •          | 3.112                  |             |  |
| - ME22 KALLO (1-1  | , 1.37                 |            |                                  |            |                        |             |  |
|  |                        |            |                                  |            |                        |             |  |
|  |                        |            |                                  |            |                        |             |  |
| 21   | EGENERATOR             | BATA       |                                  |            |                        |             |  |
| ,  |                        |            |                                  |            |                        |             |  |
| COLD S   |                        | OT SIDE    |                                  |            |                        |             |  |
|  | . 24                   | 18.84      |                                  |            |                        |             |  |
|  |                        | 285.59     |                                  |            |                        |             |  |
|  | . 41                   | 1.46       |                                  |            |                        |             |  |
| FLOW 3   | . <b>98</b><br>0 . 3 9 | 2.04       |                                  |            |                        |             |  |
| NTU  | 0.62                   |            |                                  |            |                        |             |  |
| SRATIO   | 3.65                   |            |                                  |            |                        |             |  |
| SMIN   | 7.26                   |            |                                  |            |                        |             |  |
| REGEN Q  | 2072.05                |            |                                  |            |                        |             |  |
|  |                        |            |                                  |            |                        |             |  |

### TABLE 55. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 10% OF DESIGN THRUST LEVEL

|  |              |  | E PARAMETER        |                                    |                |  |
|--|--------------|--|--------------------|------------------------------------|----------------|--|
| CHAMI  | BER PRESSI   | URE  |                    | 173.1                              |                |  |
| VAC I  | ENGINE TH    | RUST   |                    | 2000.                              |                |  |
|  | VAC. ISP     | FLOH RATE                                      |                    | 479. <b>0</b><br>4.2               |                |  |
|  | T AREA       | LOW KAIL                                       |                    | 5.547                              |                |  |
|  | E AREA R     |  |                    | 1000.                              |                |  |
|  | Æ MIXTURI    |  | no.                | 6.86                               |                |  |
|  |              | E COOLANT                                      |                    | 142.<br>841.                       |                |  |
| ETA (  |              | _ 000027411                                    |                    | 0.993                              |                |  |
| CHAMI  | BER/NOZZLI   | E <b>Q</b>                                     |                    | 1800.                              |                |  |
|  |              |  | CONDITIONS         | 49.5                               |                |  |
|  | * FUEL       | SYSTEM CO                                      | NDITIONS .         |                                    |                |  |
| STATION  |              | TEMP   | FLOH               | ENTHALPY                           | DENSITY        |  |
| B.P. INLET<br>B.P. EXIT  | 18.6<br>22.7 | 37.4   | 0.60               | -107.5<br>-107.2                   | 4.37<br>4.37   |  |
| PUMP INLET   | 22.7         | 37.4<br>37.4                                   | 0.60<br>3.60       | -107.2                             | 4.37           |  |
| IST STAGE EXIT   | 162.8        | 41.1   | 0.60               | - 95 . 8                           | 4.32           |  |
| 2ND STAGE EXIT   | 299.4        | 44.2   | 0.60               | -83.1                              | 4.27<br>4.23   |  |
| PUMP EXIT COLD REGEN IN  | 432.3        | 47.3<br>47.3                                   |                    | -71.6<br>-71.6                     | 4.23           |  |
| COLD REGEN EX  | 428.9        | 47.3<br>276.7                                  | 0.60<br>0.60       | 816.4                              | 0.29           |  |
| COOLANT IMPET  | 478.9        | 276.   | 0.60               | 816.4                              | 0.29           |  |
| COOLANT EXIT   | 286.9        | 1118.1<br>1118.2<br>1118.7<br>1118.2<br>1112.0 | 0.60<br>0.37       | 3831.7<br>3831.7                   | 0.05<br>0.05   |  |
| TBV INLET TBV EXIT   | 207.8        | 1118.7   | 0.37               | 3831.7                             | 0.03           |  |
| LOX TRB INLET  | 277.9        | 1118.2   | 0.23               | 3831.7<br>3809.7                   | 0.05           |  |
| LOX TRB EXIT   | 263.3        | 1112.0   | 0.23               |                                    | 0.04           |  |
| H2 TRB INLET   | 263.3        | 1112.0<br>1085 R                               | 0.23<br>0.23       | 38 <b>29.</b> 7<br>371 <b>7.</b> 4 | 0.04<br>0.04   |  |
| H2 TRB EXIT H2 TRB DIFF H2 BST TRB IN H2 BST TRB EXIT H2 BST TRB DIFF                    | 210.3        | 1085.8   | 0.23               | 3717.4                             | 0.04           |  |
| H2 BST TRB IN  | 209.7        | 1085.8   | 0.23               | 3717.4                             | 0.04           |  |
| H2 BST TRB EXIT  | 209.2        | 1085.6   | 0.23               | 3717.4<br>3716.5<br>3716.5         | 0.04<br>0.04   |  |
| HZ BST TRB DIFF  | 208.3        | 1085.6   | 0.23               | 3716.5                             | 0.04           |  |
| 02 BST TRB IN<br>02 BST TRB EXIT<br>02 BST TRB DIFF<br>H2 TANK PRESS<br>GOX HEAT EXCH IN | 208.1        | 1085.5   | 0.23               | 3716.1                             | 0.04           |  |
| 02 BST TRB DIFF  | 208.0        | 1085.5   | 0.23               | 3716.1                             | 0.04           |  |
| H2 TANK PRESS  | 18.6         | 1107.3   | 0.0004             | 3787.1<br>3787.1                   | 0.0032         |  |
| GOX HEAT EXCH OUT  | 207.5        | 1104.8   | 0.23               | 3783.3                             | 0.04           |  |
| HOT REGEN IN   | 207.5        |  | 0.23               | 3783.3                             | 0.04           |  |
|  | 205.9        | 449.8  | 0.23               | 14 <b>82.</b> 7<br>2925.1          | 0.09<br>0.04   |  |
| FSV INLET<br>FSV EXIT  | 198.1        | 857.8<br>857.9                                 | 0.60               | 2925.1                             | 0.04           |  |
|  | 195.2        | 857.9  | 0.60               | 2925.1                             | 0.04           |  |
| CHAMBER  | 173.1        |  |                    |                                    |                |  |
| CTATION  |              |  | CONDITIONS         | ENTHALPY                           | DENSITY        |  |
| 5 5 114 ET   | 17.0         | 1.27   | 7 6 9              | 61.1                               | 71.17          |  |
| B.P. EXIT  | 21.6         | 162.7  | 3.59               | 61.1                               | 71.17          |  |
| PUMP INLET   | 21.6         | 162.7  | 5.59               | 61.1                               | 71.17          |  |
| PUMP EXIT  02 TANK PRESS   | 16.0         | 162.7<br>162.7<br>162.7<br>165.1<br>400.0      | 3.59<br>9.01       | 62.5<br>204.8                      | 71.03<br>0.12  |  |
| POSV INLET   | 293.3        | 165.1  | 2.87               | 62.5                               | 71.03          |  |
| POSV EXIT  | 234.6        | 105.4  | 2.87               | 62.5                               | 70.93          |  |
| OCV INLET  | 293.3        | 165.1<br>165.6                                 | 0.70<br>0.70       | 62.5<br>62.5                       | 71.03<br>70.83 |  |
| PRIMARY INJ  | 173.2        | 105.4  | 2.87               | 62.5                               | 70.92          |  |
| SECONDARY INJ  | 173.2        | 105.0  | 0.70               | 42.5                               | 70.83          |  |
| CHAMBER  | 173.1        |  |                    |                                    |                |  |
|  |              | VE DATA  |                    |                                    |                |  |
| VAL <b>VE</b>  | DELTA P      |  | FLOW               | S BYPASS                           |                |  |
| TBV  |              | 3.3.5  | 2.27               | 61.41                              |                |  |
| FSV  |              | 5.8  | o 0                |                                    |                |  |
| POSV<br>CEV  | .20.         | 0.0 <b>07</b><br>0.011                         | 37<br>3.7 <b>0</b> |                                    |                |  |
|  |              | ECTOR DATA                                     |                    |                                    |                |  |
|  |              |  |                    |                                    |                |  |
| • FUEL   |              | IXU - UXI:<br>Vram)                            | D 4<br>SECOND      |                                    |                |  |
| DELP MAN 2.98  |              | .54  | 3.01               |                                    |                |  |
| DELP INJ 19.10   | : 50         | 1.52   | 3.09               |                                    |                |  |
| AREA I.05  |              | 3.07   | 0.41               |                                    |                |  |
| FLOM 0.60  | , .          | .37  | 0.70               |                                    |                |  |

TABLE 55. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 10% OF DESIGN THRUST LEVEL (CONTINUED)

|                              | . TURBONACHINER | Y PERFORMANCE DA  | TA #                   |                       |                 |  |
|------------------------------|-----------------|---|------------------------|-----------------------|-----------------|--|
|                              |                 | ************  |                        |                       |                 |  |
| *********                    |                 |   | <b>国际国际基本系统法系统资本系统</b> |                       |                 |  |
| # H2 BOOST 1                 |                 |   | 2 BOOST PU             |                       |                 |  |
| *********                    |                 |   | *******                |                       |                 |  |
| EFF ICIENCY                  | 0.301           |   | ENCY                   |                       |                 |  |
| HORSEPONER                   | . •             | HORSEP  |                        | 0.                    |                 |  |
| SPEED (RPM)                  | 8140.           |   | (RPM)                  | 8140.                 |                 |  |
| MEAN DIA (IN)                |                 |   | D                      | 1632.                 |                 |  |
| EFF AREA (IN2)               |                 |   | (FT)                   | 133.                  |                 |  |
| U/C (IDEAL)                  |                 | DIA.  | (IN)                   | 2.18                  |                 |  |
| MAX TIP SPEED                | 46.             | LIE ZEI   | EED                    | 77.                   |                 |  |
| STAGES                       | 1.              | VOL. FI   | LOM                    | 61.                   |                 |  |
| DELTA H (ACT)                |                 | HEAD C  | DEF                    | 0.712                 |                 |  |
| GAMMA                        | 1.40            | FLOW C  | JEF                    | 0.115                 |                 |  |
| PRESS RATIO (T/1             | 7) 1.61         |   |                        |                       |                 |  |
|                              |                 |   |                        | _                     |                 |  |
| **********                   |                 |   | H2 PUMP                |                       |                 |  |
| # H2 TURBINE                 |                 |   |                        |                       |                 |  |
| *********                    |                 |   | *********              |                       | STAGE THREE     |  |
|                              | STAGE 1 STAGE   |   |                        |                       | HARRESTERNA     |  |
|                              | ******          |   | 0 /00                  | 0 /06                 | 0.582           |  |
| EFFICIENCY<br>HORSEPONER     | 0.3/1 0.41      | 7 EFFICIENCY<br>. HORSEPOWER<br>. SPEED (RPM)                                   | U.489                  | U.475                 | 1.592           |  |
| MINSENDER CORE               | 10. 14          | . MURSEYUMER  | 72027                  | 10.                   | 10.<br>22022    |  |
| SPEED (RPM)                  | 32027. 32027    | . SPEED (KPM)   | 32027.                 | 32021.<br>/EE         | 32 <b>0</b> 27. |  |
| REAN DIA (IN)                | 2.78 2.7        | o bear (cr.   | 448.                   | 433.<br>(EGA          | 4498.           |  |
| EFF AREA (INZ)               | 0.4             | U MCAU (FT)   | 4653.                  | 4580.                 | 4478.<br>3.43   |  |
| U/L (IUEAL)                  | 700 ***         | DIM. (IN)   | 2.43                   | 3.43<br>/20           | 479.            |  |
| MAX TIP SPEED                | 700. 788        | SPEED (RPH) S SPEED HEAD (FT) DIA. (IN) TIP SPEED VOL. FLOW HEAD COEF FLOW COEF | 4/7.                   | 417.<br>42            | 417.            |  |
| CAMMA (ACT)                  | 140 14          | A HEAD COEF   | 0 652                  | 63.<br>0.642<br>0.040 | 0.631           |  |
| DECC DATIONATION             | 1.40 1.4        | 7 FINH COEF   | 0.032                  | 0.040                 | 0.062           |  |
| PRESS RATIONT                | 1.54 1.5        | / I LON COLI  | 0.007                  | 0.012                 |                 |  |
| ********                     |                 |   |                        |                       |                 |  |
| * 02 BOOST T                 |                 |   | BOOST PU               |                       |                 |  |
| ********                     |                 |   | *****                  |                       |                 |  |
| EFFICIENCY                   | 0.322           | EFF1C16   | NCY                    | 0.536                 |                 |  |
| HORSEPONER                   |                 | HORSEPO   |                        | 0.                    |                 |  |
| SPEED (RPM)                  | 2117.           |   | (RPM)                  | 2117.                 |                 |  |
| MEAN DIA (IN)                | 3.68            | S SPEED   | )                      | 1633.                 |                 |  |
| FEE ADEA (INC)               | 3.60            |   | (FT)                   | 11.                   |                 |  |
| U/C (IDEAL) MAX TIP SPEED    | 0.514           |   | (IN)                   | 2.44                  |                 |  |
| MAX TIP SPEED                | 34.             | TIP SPE   |                        | 23.                   |                 |  |
| STAGES                       | 1.              | VOL. FL   | _OM                    | 23.                   |                 |  |
| DELTA H (ACT)                | 0.42            | HEAD CO   | DEF                    | 0.717                 |                 |  |
| GAMMA                        | 1.40            | FLOW CO   |                        | 0.117                 |                 |  |
| PRESS RATIO (T/T             | 1.00            |   |                        |                       |                 |  |
|                              |                 |   |                        |                       |                 |  |
| *********                    |                 |   | ******                 |                       |                 |  |
| ■ 02 TURBINE                 | •               |   | 02 PUMP #              |                       |                 |  |
| ********                     |                 |   | ******                 |                       |                 |  |
| EFFICIENCY                   | 0.371           |   | NCY                    |                       |                 |  |
| HORSEPOWER                   | 7.              | HORSEPO   | WER                    | 7.                    |                 |  |
| SPEED (RPM)<br>MEAN DIA (IN) | 21785.          | SPEED   | (RPM)                  | 21785.                |                 |  |
| MEAN DIA (IN)                | 2.78            | S SPEEL   | )                      | 911.                  |                 |  |
| EFF AREA (IN2)               | 0.43            | HEAD  | (FT)<br>(IN)           | 552.                  |                 |  |
| U/C (IDEAL)                  | 0.153           |   |                        | 1.92                  |                 |  |
| MAX TIP SPEED                | 264.            | TIP SPE   |                        | 182.                  |                 |  |
| STAGES                       | 1.              | VOL. FL   |                        | 23.                   |                 |  |
| DELTA H (ACT)                | 21.98           | HEAD CO   |                        | 0.534                 |                 |  |
| GAMMA                        | 1.40            | FLOW CO   | DEF                    | 0.055                 |                 |  |
| PRESS RATIO (T/T             | 1.06            |   |                        |                       |                 |  |
|                              |                 |   |                        |                       |                 |  |
|                              |                 |   |                        |                       |                 |  |
|                              |                 |   |                        |                       |                 |  |
|                              | EGENERATOR DATA |   |                        |                       |                 |  |
|                              | ************    |   |                        |                       |                 |  |
| COLD S                       |                 |   |                        |                       |                 |  |
|                              | .82 1.6         |   |                        |                       |                 |  |
|                              | .44 -654.9      |   |                        |                       |                 |  |
|                              | .41 1.4         |   |                        |                       |                 |  |
|                              | .60 0.2         | ,   |                        |                       |                 |  |
| EFFECTIVENESS                | 0.62            |   |                        |                       |                 |  |
| NTU                          | 1.18            |   |                        |                       |                 |  |
| CRATIO                       | 0.35            |   |                        |                       |                 |  |
| CMIN                         | 0.81            |   |                        |                       |                 |  |
| REGEN Q                      | 530.04          |   |                        |                       |                 |  |
|                              |                 |   |                        |                       |                 |  |

TABLE 56. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 5% OF DESIGN THRUST LEVEL

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 86.0   |
|---------------------------|--------|
| VAC ENGINE THRUST         | 1000.  |
| DEL. VAC. ISP             | 478.5  |
| TOTAL ENGINE FLON RATE    | 2.1    |
| THROAT AREA               | 5.547  |
| NOZZLE AREA RATIO         | 1006.6 |
| ENGINE MIXTURE RATIO      | 6.00   |
| CHAMBER/NOZZLE COOLANT DP | 53.    |
| CHAMBER/NOZZLE COOLANT DT | 929.   |
| ETA C.                    | 0.993  |
| CHAMBER/NOZZLE Q          | 996.   |

| <b></b>           | DER TOUR |            |             |          |         |
|-------------------|----------|------------|-------------|----------|---------|
|                   | ENGINE   | STATION    | CONDITIONS  |          |         |
|                   |          |            | ********    |          |         |
|                   |          |            | * SHOITIGHS |          |         |
| STATION           | PRESS    | TEHP       | FLOH        | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6     | 37.4       | 0.30        | -107.5   | 4.37    |
| B.P. EXIT         | 20.1     | 37.4       | 0.30        | -107.4   | 4.37    |
| PUMP INLET        | 20.1     | 37.4       | 0.30        | -107.4   | 4.37    |
| IST STAGE EXIT    | 78.0     | 39.4       | 0.30        | -161.5   | 4.34    |
| 2ND STAGE EXIT    | 134.6    | 41.0       | 0.30        | -95.8    | 4.30    |
| PUMP EXIT         | 189.8    | 42.6       | 0.30        | -90.2    | 4.27    |
| COLD REGEN IN     | 189.6    | 42.6       | 0.30        | -98.2    | 4.27    |
| COLD REGEN EX     | 188.2    | 276.7      | 0.30        | 818.8    | 0.13    |
| COOLANT INLET     | 188.2    | 276.7      | 0.30        | 818.8    | 0.13    |
| COOLANT EXIT      | 135.2    | 1205.5     | 0.30        | 4132.8   | 0.02    |
| THY INLET         | 130.1    | 1205.6     | 0.21        | 4132.8   | 0.02    |
| THE EXIT          | 104.7    | 1205.8     | 0.21        | 4132.8   | 0.02    |
| LOX TRB INLET     | 130.1    | 1205.6     | 0.09        | 4132.8   | 0.02    |
| LOX TRB EXIT      | 124.6    | 1201.7     | 0.09        | 4119.1   | 0.02    |
| HZ TRB INLET      | 124.6    | 1201.7     | 0.09        | 4119.1   | 0.02    |
| H2 TRB EXIT       | 106.0    | 1186.1     | 0.09        | 4864.1   | 0.02    |
| HZ TRB DIFF       | 105.7    | 1186.1     | 0.09        | 4864.1   | 0.02    |
| HZ BST TRB IN     | 105.5    | 1186.l     | 0.09        | 4064.1   | 0.02    |
| H2 BST TRB EXIT   | 105.3    | 1186.0     | 0.09        | 4063.6   | 0.02    |
| H2 BST TRB DIFF   | 105.1    | 1186.0     | 0.09        | 4063.6   | 0.02    |
| OZ BST TRB IN     | 104.9    | 1186.0     | 0.10        | 4063.6   | 0.02    |
| OZ BST TRB EXIT   | 104.8    | 1185.9     | 0.10        | 4063.4   | 0.02    |
| OZ BST TRB DIFF   | 104.8    | 1185.9     | 0.10        | 4063.4   | 0.02    |
| HZ TANK PRESS     | 18.6     | 1200.2     | 0.0002      | 4111.2   | 0.0029  |
| GOX HEAT EXCH IN  | 104.7    | 1199.6     | 0.09        | 4111.2   | 0.02    |
| GOX HEAT EXCH OUT | 104.7    | 1198.3     | 0.09        | 4186.5   | 0.02    |
| HOT REGEN IN      | 104.7    | 1198.3     | 0.09        | 4104.5   | 0.02    |
| HOT REGEN EX      | 104.1    | 371.8      | 0.09        | 1190.0   | 0.05    |
| FSV INLET         | 104.1    | 942 3      | 0.30        | 3215.6   | 0.02    |
| FSV EXIT          | 99.B     | 943        | 0.30        | 3215.6   | 0.02    |
| CHAMBER INJ       | 98.2     | 942        | 0.30        | 3215.6   | 0.02    |
| CHAMBER           | 16.0     |            |             |          |         |
| *                 |          |            |             |          |         |
|                   | * OXY    | SEN SYSTEM | CONDITIONS  | 5 .      |         |
| STATION           | PRESS    | TEMP       | FLOH        | ENTHALPY | DENSITY |
| 3.P. INLET        | 16.0     | 162.7      | 1.79        | 61.1     | 71.17   |
| B.P. EXIT         | 17.0     | 162.7      | 1.79        | 61.1     | 71.17   |
| PUMP INLET        | 17.0     | 162.7      | 1.79        | 61.1     | 71.17   |
| PUMP EXIT         | 132.4    | 164.0      | 1.79        | 61.8     | 71.07   |
| 02 TANK PRESS     | 16.0     | 400.0      | 0.00        | 294.8    | 0.12    |
| POSV INLET        | 132.3    | 164.0      | 1.78        | 61.8     | 71.07   |
| POSV EXIT         | 109.8    | 164.1      | 1.78        | 61.8     | 71.03   |
| OCV INLET         | 132.3    | 164.0      | 0.01        | 61.8     | 71.07   |
| OCV EXIT          | 86.0     | 164.2      | 0.01        | 61.8     | 70.99   |
| PRIMARY INJ       | 105.5    | 164.1      | 1.78        | 61.8     | 71.02   |
| SECONDARY INJ     | 86.0     | 164.2      | 0.01        | 61.8     | 70.99   |
| CHAMBER           | 86.2     |            |             |          |         |
|                   |          |            |             |          |         |
|                   |          | VE DATA    |             |          |         |
|                   |          | ******     |             |          |         |
| VAL.VE            | DELTA P  | AREA       | FLOW        | % BYPASS |         |
| TBV               | 25.      | 3.484      | 0.21        | 68.83    |         |
| FSV               | 4.       | 1.528      | 0.30        |          |         |
| POSV              | 23.      | 0.067      | 1.78        |          |         |
| OCY               | 46.      | 0.000      | 0.01        |          |         |
|                   |          |            |             |          |         |
|                   | INJ      | CTOR DATA  |             |          |         |

+ OXID +
PRIMARY SECOND
2.15 0.00
19.31 0.00
3.37 0.41
1.78 0.01

\* FUEL \*

10.62

0.30

DELP MAN

AREA FLOM

TABLE 56. — ADVANCED ENGINE PARAMETRIC STUDY FULL-EXPANDER ENGINE WITH A HYDROGEN REGENERATOR 5% OF DESIGN THRUST LEVEL (CONTINUED)

|  | - TURBON    | ACHINERY P      | ERFORMANCE DATA      | A =        |                     |             |
|--|-------------|-----------------|----------------------|------------|---------------------|-------------|
|  |             | ***********     |                      |            |                     |             |
|  |             |                 | **********           |            |                     |             |
| # H2 BOOST TURBINE #   |             |                 | # H2 BOOST PUMP #    |            |                     |             |
| *********  |             |                 |                      |            |                     |             |
| EFFICIENCY   | 0.20        | ,               | EFFICIE)             | MCY<br>MED | 0.468               |             |
| HOR SEPOHER SPEED (RPH)  | 8.<br>4798. | •               | HORSEPOI<br>SPEED    | (DOM)      | 0.<br>4798.         |             |
| MEAN DIA (IN)  |             |                 | S SPEED              |            | 1426.               |             |
| FEE ADEA (1M2)   | 2 41        |                 | HEAD                 | (FT)       | 49.                 |             |
| U/C (IDEAL)  | 0.476       |                 | HEAD<br>DIA.         | (IN)       | 2.18                |             |
| MAX TIP SPEED  | 27.         |                 | TIP SPEE             | D          | 46.                 |             |
| STAGES   | 1.          |                 | VOL. FLO             |            | 31.                 |             |
| DELTA H (ACT)  |             |                 |                      |            | 0.765               |             |
| GAHHA  | 1.37        | ,               | HEAD COE<br>FLOH COE | F          | 0.097               |             |
| PRESS RATIO (T/1   | r) 1.01     |                 |                      |            |                     |             |
|  |             |                 |                      |            |                     |             |
| *********  |             |                 |                      | ******     |                     |             |
| ■ H2 TURBINE   |             |                 |                      | H2 PUMP    |                     |             |
| *******  | ***         |                 | **                   |            |                     |             |
|  | STAGE I     | STAGE 2         | 51                   |            |                     | STAGE THREE |
| CECTATENAN   | A 277       | 0.716           | ESSICIENCY           | 0.619      | 0.628               | 0.430       |
| HUDSEDUMED   | 4.273       | 7               | HORSEPOWER           | 2.         | 2.                  | 2.          |
| EFFICIENCY HORSEPONER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 20529.      | 20529.          | SPEED (RPM)          | 20529      | 20529               | 20529.      |
| MEAN DIA (IN)  | 2.78        | 2.78            | S SPEED              | 394        | 400.                | 407.        |
| EFF AREA (IN2)   | 8.31        | 0.40            | HEAD (FT)            | 1915.      | 1886.               | 1855.       |
| U/C (IDEAL)  | 0.106       | 0.125           | DIA. (IN)            | 3.43       | 3.43                | 3.43        |
| MAX TIP SPEED  | 249.        | 249.            | TIP SPEED            | 307.       | 307.                | 307.        |
| DELTA H  | 30.         | 25.             | VOL. FLOW            | 31.        | 31.                 | 31.         |
| GAMMA (ACT)  | 1.37        | 1.37            | HEAD COEF            | 0.653      | 0.644               | 0.633       |
| PRESS RATIO(T/T  | 1.34        | 1.37            | FLOW COEF            | 0.031      | 0.031               | 0.032       |
|  |             |                 |                      |            |                     |             |
| *********  |             |                 |                      | *********  |                     |             |
| # 02 BOOST T   |             |                 |                      | BOOST PUR  |                     |             |
|  |             |                 |                      |            |                     |             |
| EFFICIENCY<br>HORSEPONER   | U.136<br>8. |                 | EFFICIEN<br>HORSEPON | FR         | 0.601               |             |
| SPEED (RPM)  | 934.        |                 | SPEED                | (RPM)      | 0.<br>934.<br>1836. |             |
| MEAN DIA (IN)  |             |                 | S SPEED              |            | 1836.               |             |
| CEC 4054 (1N2)   | 7 46        |                 |                      |            | 2.                  |             |
| U/C (IDEAL)  | 0.514       |                 | HEAD<br>DIA.         | (IN)       | 2.44                |             |
| MAX TIP SPEED  |             |                 | TIP SPEE             | Ď          | 10.                 |             |
| STAGES   | ı.          |                 | VOL. FLO             | H          | 11.                 |             |
| DELTA H (ACT)  | 0.19        |                 | HEAD COE<br>FLOW COE | F          | 0.667               |             |
| G <b>AMMA</b>  | 1.3/        |                 | FLOW COE             | F          | 0.133               |             |
| PRESS RATIO (T/T   | 1.00        |                 |                      |            |                     |             |
| *********  |             |                 |                      |            |                     |             |
| # 02 TURBINE   |             |                 |                      | 2 PUMP ×   |                     |             |
| ***********  |             |                 |                      | *****      |                     |             |
| EFFICIENCY   | 0.271       |                 | EFFICIEN             | CY         | 0.423               |             |
| HORSEPOWER   | 2-          |                 | EFFICIEN<br>HORSEPOW | ER         | 2.                  |             |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 14146.      |                 | SPEED                | (RPM)      | 14146.              |             |
| MEAN DIA (IN)  | 2.78        |                 | S SPEED              |            | 796.                |             |
| EFF AREA (1N2)   | 0.43        |                 | HEAD<br>DIA.         | (FT)       | 234.                |             |
| U/C (IDEAL) MAX TIP SPEED  | 0.108       |                 |                      |            | 1.92                |             |
| MAX TIP SPEED  | 172.        |                 | TIP SPEE             |            | 118.                |             |
| STAGES<br>DELTA H (ACT)  | 1.          |                 | VOL. FLO             |            | 11.<br>0.537        |             |
| GAMMA (ACT)  | 13.07       |                 | FLOW COE             |            | 0.042               |             |
| PRESS RATIO (T/T   |             |                 | / LON COL            | •          | 0.042               |             |
| TRESS NATIO (17)   | ,           |                 |                      |            |                     |             |
|  |             |                 |                      |            |                     |             |
|  |             |                 |                      |            |                     |             |
|  | EGENERATO   |                 |                      |            |                     |             |
|  | ****        |                 |                      |            |                     |             |
|  |             | OT SIDE         |                      |            |                     |             |
|  | . 45        | 0.56            |                      |            |                     |             |
|  |             | -826.44<br>1.46 |                      |            |                     |             |
|  | .41<br>.30  | 0.09            |                      |            |                     |             |
| EFFECTIVENESS  | . 30        |                 |                      |            |                     |             |
| NTU  | 1.54        |                 |                      |            |                     |             |
| CRATIO   | 0.28        |                 |                      |            |                     |             |
| CMIN   | 0.33        |                 |                      |            |                     |             |
| REGEN Q  | 271.50      |                 |                      |            |                     |             |
|  |             |                 |                      |            |                     |             |
|  |             |                 |                      |            |                     |             |

# APPENDIX D OFF-DESIGN MIXTURE RATIO CYCLES

Off-design mixture ratio cycle data are presented in Tables 57 through 68.

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### TABLE 57. — SPLIT-EXPANDER CYCLE — O/F = 5.0

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1370.7 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 16476. |
| DEL. VAC. ISP             | 477.1  |
| TOTAL ENGINE FLOW RATE    | 34.5   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1999.0 |
| ENGINE MIXTURE RATIO      | 5.00   |
| CHAMBER/NOZZLE COOLANT DP | 467.   |
| CHAMBER/NOZZLE COOLANT DT | 790.   |
| ETA C#                    | 0.793  |
| CHAMBER /NO.27LE D        | 8504   |

### ENGINE STATION COMDITIONS

|                                    | ****   | *******   | ********** |          |         |
|------------------------------------|--------|-----------|------------|----------|---------|
|                                    | * FUEL | SYSTEM CO | MOITIONS . |          |         |
| MOITATE                            | PRESS  | TEMP      | FLON       | ENTHALPY | DENSITY |
| B.P. INLET                         | 18.6   | 37.4      | 5.76       | -107.5   | 4.37    |
| B.P. EXIT                          | 93.0   |           |            | -103.4   | 4.39    |
| PUMP INLET                         | 93.0   |           | 5.76       | -103.4   | 4.39    |
| IST STAGE EXIT                     |        |           | 5.76       | 17.5     | 4.36    |
| JBV INLET                          | 1878.8 | 66.9      |            | 17.5     | 4.33    |
| JBV EXIT                           | 1547.9 | 69.4      |            | 17.5     | 4.09    |
| 2ND STAGE EXIT                     | 3070.1 |           |            | 96.6     | 4.34    |
| PUMP EXIT                          | 4185.3 | 102.2     | 2.88       | 172.8    | 4.35    |
| COOLANT INLET                      | 4140.5 | 102.6     | 2.88       | 172.8    | 4.33    |
| COOLANT EXIT                       | 3673.7 | 892.5     | 2.88       | 3126.5   | 0.70    |
| TBV INLET                          | 3639.2 | 892.7     | 0.03       | 3126.5   | 0.70    |
| TBV EXIT                           | 1618.4 | 906.1     | 0.03       | 3126.5   | 0.32    |
| LOX TRB INLET                      | 3639.2 | 892.7     | 2.85       | 3126.5   | 0.70    |
| LOX TRB EXIT                       | 3204.7 | 869.9     | 2.85       | 3036.0   | 0.63    |
| H2 TRB INLET                       |        |           |            |          |         |
| H2 TRB EXIT                        |        |           |            |          |         |
| H2 TRB DIFF                        | 1701.8 | 766.2     |            |          | 0.40    |
| HZ BST TRB IN                      | 1683.2 | 766.3     | 2.85       | 2634.8   | 0.39    |
| H2 BST TRB EXIT                    | 1662.0 | 764.1     | 2.85       |          | 0.39    |
| H2 BST TRB EXIT<br>H2 BST TRB DIFF | 1657.4 | 764.1     | 2.85       | 2626.5   | 0.39    |
| OZ BST TRB IN                      | 1639.2 | 764.2     | 2.85       | 2626.5   | 0.38    |
| OZ BST TRB EXIT                    |        |           |            | 2622.1   | 0.38    |
| O2 BST TRB DIFF                    |        |           |            | 2622.1   | 0.38    |
| H2 TANK PRESS                      | 18.6   | 774.2     | 8.0060     | 2627.1   |         |
| GUX HEAT EXCH IN                   | 1618.4 | 764.5     | 2.85       | 2627.1   | 0.38    |
| GOX HEAT EXCH DUT                  | 1610.4 | 763.9     | 2.85       | 2624.8   | 0.38    |
| MIXER HOT IN                       | 1610.4 | 763.9     | 2.85       | 2624.8   | 0.38    |
| MIXER COLD IN                      |        |           |            | 17.5     |         |
| MIXER OUT                          | 1530.8 | 402.0     | 5.76       | 1314.6   | 0.67    |
| FSV INLET                          |        |           |            |          |         |
|                                    |        |           |            | 1314.6   | 0.65    |
| CHAMBER INJ                        | 1476.7 | 402.1     | 5.76       | 1314.6   | 0.64    |
| CHAMBER                            | 1371.1 |           |            |          |         |
|                                    |        |           |            |          |         |

|               | * OXY  | GEN SYSTEM | CONDITION | S =      |         |
|---------------|--------|------------|-----------|----------|---------|
| STATION       | PRESS  | TEMP       | FLON      | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7      | 28.83     | 61.9     | 70.99   |
| B.P. EXIT     | 138.7  | 165.4      | 28.63     | 62.4     | 70.83   |
| PUMP INLET    | 138.7  | 165.4      | 28.83     | 62.4     | 70.83   |
| PUMP EXIT     | 2647.8 | 177.8      | 28.83     | 71.3     | 71.24   |
| 02 TANK PRESS | 16.0   | 400.0      | 9.05      | 204.7    | 0.12    |
| POSV INLET    | 2630.8 | 177.8      | 6.09      | 71.3     | 71.22   |
| POSV EXIT     | 1627.3 | 181.7      | 6.09      | 71.3     | 69.63   |
| OCV INLET     | 2630.8 | 177.8      | 22.68     | 71.3     | 71.22   |
| OCV EXIT      | 1481.8 | 182.3      | 22.68     | 71.3     | 69.40   |
| PRIMARY INJ   | 1580.4 | 181.9      | 6.09      | 71.3     | 69.56   |
| SECONDARY INJ | 1461.5 | 182.4      | 22.68     | 71.3     | 69.36   |
| CHAMBER       | 1370.6 |            |           |          |         |

|       | VAL     | VE DATA |       |          |
|-------|---------|---------|-------|----------|
|       | ***     | *****   |       |          |
| VALVE | DELTA P | AREA    | FLON  | * BYPASS |
| JBV   | 348.    | 0.114   | 2.88  | 50.00    |
| TBV   | 2021.   | 0.002   | 0.03  | 1.00     |
| FSV   | 39.     | 1.654   | 5.76  |          |
| POSV  | 1004.   | 0.034   | 6.09  |          |
| ocv   | 1149.   | 0.119   | 22.68 |          |

#### INJECTOR BATA \*\*\*\*\*\*\*\*\*

|      |     | • FUEL • | * dixo * |        |  |  |
|------|-----|----------|----------|--------|--|--|
|      |     |          | PRIMARY  | SECONS |  |  |
| DELP | MAN | 15.76    | 23.31    | 10.09  |  |  |
| DELP | INJ | 90.19    | 209.80   | 90.77  |  |  |
| ARÉA |     | 1.14     | 0.08     | 0.43   |  |  |
| FLOW |     | 5.76     | 6.09     | 22.68  |  |  |

TABLE 57. — SPLIT-EXPANDER CYCLE — O/F = 5.0 (CONTINUED)

|   |            |             | ERFORMANCE DATA         |                     |                |             |
|---|------------|-------------|-------------------------|---------------------|----------------|-------------|
|   |            |             | ******                  |                     |                |             |
| *******   |            |             |                         | ******              | ***            |             |
| ■ H2 BOOST 1  | TURBINE #  |             | * H2                    | BOOST PU            | MP #           |             |
| ********  |            |             | ***                     | ******              | ***            |             |
| EFFICIENCY<br>HORSEPOHER  | 0.867      |             | EFF I CIE               | NCY                 | 0.765          |             |
| HORSEPOHER  | 33.        |             | HORSEPO                 | WER                 | 33.            |             |
| SPEED (RPM)   | 44201.     |             | SPEED                   |                     | 44201.         |             |
| MEAN DIA (IN)   | 1.90       |             | S SPEED                 |                     | 2088.          |             |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED  | 1.45       |             | HEAD<br>DIA.            | (FT)                | 2443.          |             |
| U/C (IDEAL)   | 0.512      |             | DIA.                    | (IN)                | 2.18           |             |
| MAX TIP SPEED   | 366.       |             | HP SPE                  | E D                 | 420.           |             |
| STAGES  | 1.         |             | VOL. FLO                | DW<br>              | 589.           |             |
| DELTA H (ACT)   | 8.29       |             | HEAD COL<br>FLOW COL    | EF<br>ce            | 0.445<br>0.203 |             |
| GAMMA   | 1.41       |             | FLUM CO                 | EF                  | 0.203          |             |
| PRESS RATIO (T/1  | 1.01       |             |                         |                     |                |             |
|   |            |             |                         | *****               |                |             |
|   |            |             |                         | H2 PUMP             |                |             |
| W M2 TURBINE  |            |             |                         |                     |                |             |
| <b>**********</b>   | STAGE 1    | STAGE 2     | ć.                      | TAGE ONF            | STAGE TWO      | STAGE THREE |
|   | SIMOL I    | *****       |                         | ******              | *******        | *****       |
| FEETCIENCY  | 0.818      | 0.816       | EFF ICIENCY             | 0.640               | 0.619          | 0.624       |
| HORSEPOHER  | 1614.      | 1619.       | HORSEPOWER              | 986.                | 323.           | 310.        |
| SPEED (PPM)   | 118310.    | 18310.      | SPEED (RPM)             | 118310.             | 118310.        | 118310.     |
| MEAN DIA (IN)   | 3.47       | 3.47        | S SPEED                 | 750.                | 749.           | 765.        |
| FFF AREA (IN2)  | 0.21       | 0.27        | HEAD (FT)               | 60268.              | 38125.         | 36980.      |
| U/C (IDEAL)   | 0.515      | 0.506       | DIA. (IN)               | 3.68                | 3.02           | 3.02        |
| MAX TIP SPEED   | 1792.      | 1792.       | TIP SPEED               | 1904.               | 1558.          | 1558.       |
| DELTA H   | 197.       | 204.        | VOL. FLOH               | 594.                | 298.           | 297.        |
| GAMMA (ACT)   | 1.41       | 1.41        | HEAD COEF               | 0.535               | 0.505          | 0.490       |
| EFFICIENCY HORSEPOHER PERM (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 1.33       | 1.35        | FLOW COEF               | 0.094               | 0.094          | 0.095       |
| *******   | *****      |             |                         | ******              |                |             |
| * 02 BOOST 1  | TURBINE *  |             | * 02                    | BOOST PU            | MP #           |             |
| ********  |            |             |                         | ******              |                |             |
| EFFICIENCY<br>HORSEPOWER  | 0.860      |             | EFF ICIE                | NCY<br>WER          | 0.732          |             |
| HORSEPOHER  | 18.        |             | HORSEPO                 | NCY<br>WER<br>(RPM) | 18.            |             |
| SPEED (RPM)   | 11472.     |             | SPEED                   | (RPM)               | 11472.         |             |
| MEAN DIA (IN)   | 5.21       |             | S SPEED<br>HEAD<br>DIA. |                     | 2470.          |             |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED  | 2.02       |             | HEAD                    | (F1)                | 250.<br>2.44   |             |
| U/C (IDEAL)   | 0.512      |             | TIP SPE                 | (IN)                | 122.           |             |
| MAX TIP SPEED   | 261.       |             | VOL. FL                 | LD                  | 183.           |             |
| STAGES  | 1.<br>4.43 |             | WEAD CO                 | EE.                 | 0.537          |             |
| DELTA H (ACT)   | 1.41       |             | HEAD CO                 | FF                  | 0.173          |             |
| PRESS RATIO (T/)  |            |             | TEGA CO.                | _,                  | ****           |             |
| *********   | * # 12     |             | ин                      | *******             |                |             |
| # 02 TURBINE  |            | # OZ PUMP # |                         |                     |                |             |
| ********  |            |             |                         | ******              |                |             |
| EFFICIENCY<br>HORSEPOWER  | 0.824      |             | EFFICIE                 | NCY                 |                |             |
| HORSEPOHER  | 365.       |             | HORSEPO                 | WER                 | 365.           |             |
| HORSEPOHER<br>SPEED (RPM)<br>MEAN DIA (IN)<br>EFF AREA (IN2)  | 70756.     |             | SPEED                   | WER<br>(RPM)        | 70756.         |             |
| MEAN DIA (IN)   | 3.47       |             | S SPEED                 |                     | 1587.          |             |
|   |            |             | HEAD                    | (FT)<br>(IN)        | 5070.          |             |
| U/C (IDEAL)   |            |             |                         |                     |                |             |
| MAX TIP SPEED<br>STAGES   | 1072.      |             | TIP SPE                 |                     | 592.<br>182.   |             |
| STAGES  |            |             | VOL. FL<br>HEAD CO      | UM<br>EE            | 0.465          |             |
|   |            |             |                         |                     |                |             |
| DELTA H (ACT)   | 90.48      |             | FLOW CO                 | E E                 |                |             |
| DELTA H (ACT) GAMMA PRESS RATIO (T/)  | 1.41       |             | HEAD CO<br>FLOW CO      | EF                  | 0.131          |             |

### TABLE 58. — SPLIT-EXPANDER CYCLE — O/F = 5.5

## ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1522.7 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 18600. |
| DEL. VAC. ISP             | 479.0  |
| TOTAL ENGINE FLON RATE    | 8.82   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1000.0 |
| FNGINE MIXTURE RATIO      | 5.50   |
| CHAMBER/NOZZLE COOLANT DP | 525.   |
| CHAMBER/NOZZLE COOLANT DT | 886.   |
| ETA C*                    | 0.993  |
| CHAMBER/NOZZLE Q          | 9849.  |

#### ENGINE STATION CONDITIONS

| • | • |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   | * | * |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|--|
|   |   | F | υ | E | L | S | ٧ | S | ī | Ł | М | ı | С | 0 | N | D | I | T | I | 0 | N | S | Ħ |   |   |  |

|                   | 4 FUEL | SAZIEM COL | INTITUMS . |          |         |
|-------------------|--------|------------|------------|----------|---------|
| STATION .         | PRESS  | TEMP       | FLOH       | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4       | 5.98       | -107.5   | 4.37    |
| B.P. EXIT         | 100.2  | 38.5       | 5.98       | -103.0   | 4.39    |
| PUMP INLET        | 100.2  | 38.5       | 5.98       | -103.0   | 4.39    |
| IST STAGE EXIT    | 2104.4 | 69.3       | 5.98       | 29.5     | 4.36    |
| JBV INLET         | 2060.5 | 69.7       | 2.99       | 29.5     | 4.33    |
| JBV EXIT          | 1712.9 | 72.3       | 2.99       | 29.5     | 4.09    |
| 2ND STAGE EXIT    | 3368.4 | 89.3       | 2.99       | 116.3    | 4.34    |
| PUMP EXIT         | 4596.1 | 108.2      | 2.99       | 199.9    | 4.36    |
| COOLANT INLET     | 4548.1 | 108.6      | 2.99       | 199.9    | 4.34    |
| COOLANT EXIT      | 4023.2 | 995.0      | 2.99       | 3494.2   | 0.69    |
| TBV INLET         | 3985.3 | 995.3      | 0.03       | 3494.2   | 0.69    |
| TBV EXIT          | 1789.7 | 1010.5     | 0.03       | 3494.2   | 0.32    |
| LOX TRB INLET     | 3985.3 | 995.3      | 2.96       | 3494.2   | 0.69    |
| LOX TRB EXIT      | 3510.0 | 970.0      | 2.96       | 3394.2   | 0.63    |
| HZ TRB INLET      | 3510.0 | 970.0      | 2.96       | 3394.2   | 0.63    |
| H2 TRB EXIT       | 1902.0 | 855.2      | 2.96       | 2954.4   | 0.40    |
| H2 TRB DIFF       | 1880.4 | 855.4      | 2.96       | 2954.4   | 0.39    |
| H2 BST TRB IN     | 1860.2 | 855.5      | 2.96       | 2954.4   | 0.39    |
| H2 BST TRB EXIT   | 1837.1 | 853.1      | 2.96       | 2945.3   | 0.38    |
| H2 BST TRB DIFF   | 1832.1 | 853.1      | 2.96       | 2945.3   | 0.38    |
| GZ BST TRB IN     | 1812.4 | 853.2      | 2.96       | 2945.3   | 0.38    |
| 02 BST TRB EXIT   | 1800.2 | 851.9      | 2.96       | 2940.4   | 0.38    |
| 02 BST TRB DIFF   | 1799.4 | 851.9      | 2.96       | 2940.4   | 0.38    |
| H2 TANK PRESS     | 18.6   | 865.0      | 0.0056     | 2946.0   | 0.0041  |
| GOX HEAT EXCH IN  | 1789.7 | 853.6      | 2.96       | 2946.0   | 0.38    |
| GOX HEAT EXCH OUT |        | 852.9      | 2.96       | 2943.5   | 0.37    |
| MIXER HOT IN      | 1781.0 | 852.9      | 2.96       | 2943.5   | 0.37    |
| MIXER COLD IN     | 1712.9 | 72.3       | 2.99       | 29.5     | 4.09    |
| MIXER OUT         | 1694.5 | 444.7      | 5.97       | 1479.2   | 0.66    |
| FSV INLET         | 1694.5 | 444.7      | 5.97       | 1479.2   | 0.66    |
| FSV EXIT          | 1652.6 | 444.8      | 5.97       | 1479.2   | 0.65    |
| CHAMBER INJ       | 1636.2 | 444.9      | 5.97       | 1479.2   | 0.64    |
| CHAMBER INS       | 1522.7 |            |            |          |         |
| CHIDER            |        |            |            |          |         |

|                              | * OXY  | GEN SYSTEM | CONDITIONS | \$ <b>*</b> |         |
|------------------------------|--------|------------|------------|-------------|---------|
| MOITATE                      | PRESS  | TEMP       | FLOW       | ENTHALPY    | DENSITY |
| B.P. INLET                   | 16.0   | 162.7      | 32.91      | 61.9        | 70.99   |
| B.P. EXIT                    | 143.0  | 165.3      | 32.91      | 62.4        | 70.84   |
| PUMP INLET                   | 143.0  | 165.3      | 32.91      | 62.4        | 70.84   |
| PUMP EXIT                    | 2698.8 | 177.7      | 32.91      | 71.4        | 71.31   |
| 02 TANK PRESS                | 16.0   | 400.0      | 0.06       | 204.7       | 0.12    |
| POSV INLET                   | 2676.7 | 177.8      | 5.84       | 71.4        | 71.27   |
| POSV EXIT                    | 1757.3 | 181.3      | 5.84       | 71.4        | 69.83   |
|                              | 2676.7 | 177.8      | 27.02      | 71.4        | 71.27   |
| OCV INLET                    | 1679.6 | 181.6      | 27.02      | 71.4        | 69.70   |
| OCV EXIT                     | 1714.5 | 181.5      | 5.84       | 71.4        | 69.76   |
| PRIMARY IHJ<br>SECONDARY IHJ | 1651.0 | 181.7      | 27.02      | 71.4        | 69.66   |
| CHAMBER                      | 1522.7 |            |            |             |         |

| ٧ | Α | L | ٧ | E | υ | A | Į | A |  |
|---|---|---|---|---|---|---|---|---|--|
|   |   |   |   |   |   | * | * |   |  |

|       | ***     | ***** |       |          |
|-------|---------|-------|-------|----------|
| VALVE | DELTA P | AREA  | FLOH  | % BYPASS |
| JBV   | 366.    | 0.115 | 2.99  | 50.00    |
| TBV   | 2196.   | 0.002 | 0.03  | 1.00     |
| FSV   | 42.     | 1.654 | 5.97  |          |
| POSV  | 919.    | 0.034 | 5.84  |          |
| ocv   | 997.    | 0.152 | 27.02 |          |

|          |          | INJECTOR DA | TA     |
|----------|----------|-------------|--------|
|          |          | ********    |        |
|          | * FUEL * | * (         | XID *  |
|          |          | PRIMARY     | SECOND |
| DELP HAN | 17.03    | 21.31       | 14.25  |
| DELP INJ | 96.49    | 191.80      | 128.26 |
| AREA     | 1.14     | 0.08        | 0.43   |
| FLON     | 5.97     | 5.84        | 27.02  |

TABLE 58. — SPLIT-EXPANDER CYCLE — O/F = 5.5 (CONTINUED)

|   | * TURBOMACHINERY | NANNENGERNAREN<br>PERFORMANCE DATA N<br>NANNENGERNAREN |   |
|---|------------------|--|---|
| *********   |                  | ******   |   |
| * H2 BOOST 1  |                  | * H2 BOOST F   | PUMP *  |
|   |                  | *****  |   |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)<br>MEAN DIA (IN)      | 0.865            | <b>EFFICIENCY</b>                                      | 0.765   |
| HODSEDOMER  | 38.              | HORSEPOHER<br>SPEED (RPM)<br>S SPEED                   | 38.   |
| CDEED (PPM)   | 46114            | SPEED (RPM)  | 46114.  |
| MEAN DIA (IN)   | 1.90             | S SPEED  | 3062.   |
| FEE ADEA (IN2)  | 1.45             | 15T1   | 2479  |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED                | 0.512            | DIA. (IN)  | 2.18  |
| MAX TIP SPEED   | 382.             | TIP SPEED  | 438.  |
| STAGES  | 1.               | VOL. FLOH  | 611.  |
| DELTA H (ACT)   | 9.09             | HEAD COEF  | 611.<br>0.449   |
| GAMMA   | 1.43             | HEAD COEF<br>FLON COEF                                 | 0.202   |
| PRESS RATIO (T/)  |                  |  |   |
|   | •                |  |   |
| *******   | ***              |  |   |
| # H2 TURBINE  |                  | # H2 PUH   | > *   |
| ********  |                  | <b>电子性性性性</b>  |   |
|   |                  | STAGE ON   | STAGE THO STAGE THREE   |
|   | *****            | <b>有效效性效果</b>  | 计 计优先计划分别符 化非有效化化非异异烷   |
| EFF ICIENCY   | 0.816 0.816      | EFFICIENCY 0.64  | 0.620 0.625   |
| HORSEPOHER  | 1842. 1842.      | HORSEPOHER 112   | 1. 367. 354.  |
| SPEED (RPM)   | 123580. 123580.  | SPEED (RPM) 12358                                      | o. 123580. 123580.  |
| MEAN DIA (IN)   | 3.47 3.47        | S SPEED 74   | 4. 742. 758.  |
| FFF AREA (IN2)  | 0.21 0.27        | HEAD (FT) 6609   | 5, 41839. 40624.  |
| U/C (IDEAL)   | 0.512 0.507      | DIA. (IN) 3.   | 68 3.02 3.02  |
| MAX TIP SPEED   | 1872. 1872.      | TIP SPEED 198  | B. 1628. 1628.  |
| DELTA H   | 218. 222.        | VOL. FLOW 61   | 6. 309. 308.  |
| GAMMA (ACT)   | 1.43 1.43        | HEAD COEF 0.5  | 38 0.508 0.493  |
| PRESS RATIO(T/T   | 1.33 1.35        | FLOW COEF 0.0  | E STAGE TWO STAGE THREE  1 0.620 0.625  1. 367. 354.  0.123580. 123580.  4. 762. 758.  5. 41839. 40624.  88 3.02 3.02  8. 1628. 1628.  6. 309. 308.  38 0.508 0.493  94 0.093 0.095 |
|   |                  | *****  |   |
| ********  |                  | • 02 BOOST   |   |
| # 02 BOOST  |                  | # UZ BOUST   |   |
| ********  | ******           |  | 0.757   |
| EFFICIENCY<br>HORSEPOWER                                      | 0.863            | ELLICIENCE   | 20  |
| HORSEPOWER<br>SPEED (RPM)                                     | 20.              | HORSEPOHER SPEED (RPM)                                 | 12162   |
| SPEED (RPM)   | 12162.           | S SPEED (KEN)  | 2726.   |
| MEAN DIA (IN)   | 5.21             | 5 SPEED (ET)   | 258.  |
| EFF AREA (IN2)  | 2.02             | NEAD (TI)  | 2.44  |
| MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED        | 0.512            | HEAD (FT)<br>DIA. (IN)<br>TIP SPEED                    | 130.  |
| MAX TIP SPEED   | 277.             |  | 200   |
| 2 I AGE 2   | 1.               | HEAD COSE  | 0.494   |
| DELTA H (ACT)   | 4.88             | HEAD COEF<br>FLOW COEF                                 | 0.187   |
| GAMMA PRESS RATIO (T/   |                  | TEOR COC.  |   |
| PRESS RATIO (17   | 1) 1.01          |  |   |
| *******   | ***              | *****  | **  |
| * O2 TURBIN   |                  | ■ 02 PUMP  | *   |
|   |                  | ****   |   |
| EFF1C1ENCY  | 0.818            | <b>EFFICIENCY</b>                                      |   |
| HORSEPOHER  | 419.             | HORSEPOHER   | 419.  |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)<br>MEAN DIA (IN)      | 73101.           | SPEED (RPM)<br>S SPEED                                 | 73101.  |
| MEAN DIA (IN)   | 3.47             | S SPEED  | 1728.   |
| EFF AREA (IN2)  | 0.25             | HEAD (FT)<br>DIA. (IN)                                 | 5159.   |
| EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED STAGES DELTA H (ACT) | 0.447            | DIA. (IN)  | 1.92  |
| MAX TIP SPEED   | 1107.            | TIP SPEED  | 612.  |
| STAGES  | 1.               | VOL. FLOW  | 207,  |
| DELTA H (ACT)   | 99.96            | HEAD COEF<br>FLOH COEF                                 | 0.444   |
| GAMMA   | 1.43             | FLON COEF  | 0.145   |
| PRESS RATIO (T/   | T) 1.14          |  |   |
|   |                  |  |   |

TABLE 59. — SPLIT-EXPANDER CYCLE — O/F = 6.0

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1610.7 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 20000. |
| DEL. VAC. ISP             | 480.0  |
| TOTAL ENGINE FLOW RATE    | 41.7   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.80   |
| CHAMBER/NOZZLE COOLANT DP | 583.   |
| CHAMBER/NOZZLE COOLANT DT | 1018.  |
| ETA C#                    | 0.993  |
| CHAMBER/NOZZLE Q          | 11190. |

### ENGINE STATION CONDITIONS

|                   | * FUEL | SYSTEM CO |        |          |         |
|-------------------|--------|-----------|--------|----------|---------|
| STATION           | PRESS  | TEMP      | FLOM   | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4      | 5.96   | -107.5   | 4.37    |
| B.P. EXIT         | 100.6  | 38.5      | 5.96   | -103.0   | 4.39    |
| PUMP INLET        | 100.6  | 38.5      | 5.96   | -103.0   | 4.39    |
| IST STAGE EXIT    | 2163.5 | 70.1      | 5.96   | 33.2     | 4.36    |
| JBV INLET         | 2120.0 | 70.5      | 2.98   | 33.2     | 4.33    |
| JBV EXIT          | 1808.4 | 72.9      | 2.98   | 33.2     | 4.12    |
| 2ND STAGE EXIT    | 3465.7 | 90.6      | 2.98   | 122.3    | 4.35    |
| PUMP EXIT         | 4732.3 | 110.0     | 2.98   | 208.3    | 4.37    |
| COOLANT INLET     | 4684.7 | 110.4     | 2.98   | 208.3    | 4.35    |
| COOLANT EXIT      | 4101.7 | 1128.8    | 2.98   | 3965.4   | 0.62    |
| TBV INLET         | 4060.2 | 1129.1    | 0.17   | 3965.4   | 0.62    |
| TBV EXIT          | 1884.0 | 1144.7    | 0.17   | 3965.4   | 0.30    |
| LOX TRB INLET     | 4060.2 | 1129.1    | 2.81   | 3965.4   | 0.62    |
| LOX TRB EXIT      | 3583.4 | 1101.3    | 2.81   | 3855.8   | 0.57    |
| H2 TRB INLET      | 3583.4 | 1101.3    | 2.81   | 3855.8   | 0.57    |
| H2 TRB EXIT       | 1994.0 | 976.B     | 2.81   | 3381.8   | 0.37    |
| H2 TRB DIFF       | 1972.8 | 977.0     | 2.81   | 3381.8   | 0.36    |
| H2 BST TRB IN     | 1953.0 | 977.1     | 2.81   | 3381.8   | 0.36    |
| H2 BST TRB EXIT   | 1930.3 | 974.5     | 2.81   | 3372.2   | 0.36    |
| H2 BST TRB DIFF   | 1925.4 | 974.5     | 2.81   | 3372.2   | 0.35    |
| OZ BST TRB IN     | 1906.1 | 974.7     | 2.81   | 3372.2   | 0.35    |
| OZ BST TRB EXIT   | 1894.2 | 973.3     | 2.81   | 3367.1   | 0.35    |
| O2 BST TRB DIFF   | 1893.5 | 973.3     | 2.81   | 3367.l   | 0.35    |
| H2 TANK PRESS     | 18.6   | 996.0     | 0.0048 | 3400.5   | 0.0035  |
| GOX HEAT EXCH IN  | 1884.0 | 982.9     | 2.81   | 3400.5   | 0.34    |
| GOX HEAT EXCH OUT | 1875.4 | 982.2     | 2.81   | 3397.7   | 0.34    |
| MIXER HOT IN      | 1875.4 | 982.2     | 2.81   | 3397.7   | 0.34    |
| MIXER COLD IN     | 1808.4 | 72.9      | 2.98   | 33.2     | 4.12    |
| MIXER OUT         | 1790.3 | 495.2     | 5.95   | 1667.0   | 0.63    |
| FSV INLET         | 1790.3 | 495.2     | 5.95   | 1667.0   | 0.63    |
| FSV EXIT          | 1746.5 | 495.3     | 5.95   | 1667.0   | 0.62    |
| CHAMBER INJ       | 1729.4 | 495.4     | 5.95   | 1667.0   | 0.61    |
| CHAMBER           | 1610.8 |           |        |          |         |
|                   |        |           |        |          |         |

|               | * OXY  | GEN SYSTEM | CONDITION | S =      |         |
|---------------|--------|------------|-----------|----------|---------|
| STATION       | PRESS  | TEMP       | FLOH      | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7      | 35.77     | 61.9     | 70.99   |
| B.P. EXIT     | 134.5  | 165.3      | 35.77     | 62.3     | 70.84   |
| PUMP INLET    | 134.5  | 165.3      | 35.77     | 62.3     | 70.84   |
| PUMP EXIT     | 2592.0 | 177.1      | 35.77     | 70.9     | 71.30   |
| 02 TANK PRESS | 16.0   | 400.0      | 0.06      | 204.7    | 0.12    |
| POSV INLET    | 2565.9 | 177.2      | 5.31      | 70.9     | 71.26   |
| POSV EXIT     | 1804.4 | 180.1      | 5.31      | 70.9     | 70.07   |
| OCV INLET     | 2565.9 | 177.2      | 30.40     | 70.9     | 71.26   |
| OCV EXIT      | 1808.3 | 180.1      | 30.40     | 70.9     | 70.07   |
| PRIMARY INJ   | 1769.0 | 180.2      | 5.31      | 70.9     | 70.01   |
| SECONDARY INJ | 1772.2 | 180.2      | 30.40     | 70.9     | 70.01   |
| CHAMBER       | 1610.7 |            |           |          |         |

|        | VAL     | VE DATA |       |          |  |  |  |  |  |
|--------|---------|---------|-------|----------|--|--|--|--|--|
| ****** |         |         |       |          |  |  |  |  |  |
| VALVE  | DELTA P | AREA    | FLOW  | * BYPASS |  |  |  |  |  |
| JBV    | 330.    | 0.121   | 2.98  | 50.00    |  |  |  |  |  |
| TBV    | 2176.   | 0.010   | 0.17  | 5.59     |  |  |  |  |  |
| FSV    | 44.     | 1.654   | 5.95  |          |  |  |  |  |  |
| POSV   | 762.    | 0.034   | 5.31  |          |  |  |  |  |  |
| OCV    | 758.    | 0.196   | 30.40 |          |  |  |  |  |  |

|        |     | * FUEL * |         | OXID # |
|--------|-----|----------|---------|--------|
|        |     |          | PRIMARY | SECOND |
| DELP P | MAN | 17.78    | 17.59   | 17.95  |
| DELP I | LNJ | 100.88   | 158.28  | 161.51 |
| AREA   |     | 1.14     | 0.08    | 0.43   |
| FLOW   |     | 5.95     | 5.31    | 30.40  |

TABLE 59. — SPLIT-EXPANDER CYCLE — O/F = 6.0 (CONTINUED)

|  | *******       | *****  | *********      | * *          |           |             |
|--|---------------|--------|----------------|--------------|-----------|-------------|
|  |               |        | RFORMANCE DATA |              |           |             |
|  | ******        | *****  | ******         | « #          |           |             |
| *****  | *****         |        |                | *******      |           |             |
| # H2 BOOST T   |               |        |                | BOOST PUM    |           |             |
| *******  |               |        |                | ****         |           |             |
|  |               |        | EFFICIEN       |              | 0.765     |             |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)  | 38.           |        | HORSEPOR       |              | 38.       |             |
| SPEED (RPM)  | 46119.        |        | SPEED          |              | 46119.    |             |
| MEAN DIA (IN)  | 1.90          |        | S SPEED        |              | 3044.     |             |
| EFF AREA (IN2)   |               |        | HEAD<br>Dia.   | (FT)         | 2694.     |             |
| ILC (IDEAL)  | 0.512         |        | DIA.           | (IN)         | 2.18      |             |
| U/C (IDEAL) MAX TIP SPEED  | 382.          |        | TIP SPEE       |              | 438.      |             |
| CTACES   | 1.            |        | VOL. FLO       | H            | 609.      |             |
| DELTA H (ACT)  | 9.58          |        | UE 10 COS      |              | 0.451     |             |
| GAMMA  | 1.43          |        | FLOW COE       | F            | 0.201     |             |
| PRESS RATIO (T/T   |               |        |                |              |           |             |
| FRESS RAILO (III   | ,             |        |                |              |           |             |
| ******   |               |        |                | ******       |           |             |
| # H2 TURBINE   |               |        |                | H2 PUMP      |           |             |
| *******  |               |        | **             | *******      | •         |             |
|  | STAGE 1 S     | TAGE 2 | s.             | TAGE ONE     | STAGE THO | STAGE THREE |
|  | ******        | ****   | **             | *****        | *****     | ********    |
| CEETCIENCY   | 0.804         | 0.807  | EFFICIENCY     | 0.642        | 0.620     | 0.625       |
| MODSEDOMER   | 1885.         | 1885.  | HORSEPOWER     | 1147.        | 376.      | 362.        |
| COECD (PPM)  | 124731 . 12   | 4731.  | SPEED (RPM)    | 124731.      | 124731.   | 124731.     |
| MEAN DIA (IN)  | 3.47          | 3.47   | S SPEED        | 733.         | 732.      | 746.        |
| EEE ADEA (IN?)   | 0.21          | 0.27   | HEAD (FT)      | 67999.       | 43062.    | 41841.      |
| U/C (IDEAL)  | 0.492         | 0.493  | DIA. (IN)      | 3.68         | 3.02      | 3.02        |
| MAY TIP SPEED  | 1890.         | 1890.  | TIP SPEED      | 2007.        | 1643.     | 1643.       |
| DELTA H  | 237.          | 237.   | VOL. FLON      | 613.         | 307.      | 306.        |
| CAMMA (ACT)  | 1.43          | 1.43   | HEAD COEF      | 0.543        | 0.513     | 0.499       |
| EFFICIENCY HORSEPOMER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) PRESS RATIO(T/T | 1.33          | 1.35   | FLOW COEF      | 0.092        | 0.092     | 0.093       |
| TRESS KATTOTT  |               |        |                |              |           |             |
| ********   |               |        | ***            | *****        | ***       |             |
| * 02 BOOST   |               |        |                | BOOST PU     |           |             |
| *********  | *******       |        |                | ******       |           |             |
| EFFICIENCY<br>HORSEPOWER   | 0.857         |        | EFFICIE        | NCY          | 0.764     |             |
| HUBSEBUMER   | 21.           |        | HORSEPO        | HER          | 21.       |             |
| SPEED (RPM)  | 12307.        |        | SPEED          | (RPH)        | 12307.    |             |
| MEAN DIA (IN)  | 5.21          |        | S SPEED        | l .          | 3030.     |             |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED   | 2.02          |        | HEAD           | (FT)<br>(IN) | 241.      |             |
| U/C (IDEAL)  | 0.512         |        |                |              | 2.44      |             |
| MAX TIP SPEED  | 280.          |        | TIP SPE        |              | 131.      |             |
| STAGES   | 1.            |        | VOL. FL        |              | 227.      |             |
| DELTA H (ACT)  | 5.16          |        | HEAD CO        | EF           | 0.450     |             |
| GAMMA  | 1.43          |        | FLOH CO        | EF           | 0.201     |             |
| PRESS RATIO (T/  | T) 1.01       |        |                |              |           |             |
|  |               |        |                |              |           |             |
| *****  | ***           |        |                | *****        |           |             |
| * 02 TURBIN  | E .           |        |                | O2 PUMP      |           |             |
| ******   |               |        |                | *******      |           |             |
| EFFICIENCY   | 0.804<br>436. |        | EFFICIE        | ENCY<br>DHER | 0.740     |             |
| HORSEPOWER   | 436.          |        | HORSEPO        | DHER         | 436.      |             |
| SPEED (RPM) MEAN DIA (IN)  | 73440.        |        |                | (RPH)        | 73440.    |             |
| MEAN DIA (IN)  | 3.47          |        | S SPEE         |              | 1864.     |             |
| EFF AREA (IN2)   | 0.25          |        | HEAD           | (FT)<br>(IN) | 4962.     |             |
| U/C (IDEAL)  | 0.425         |        |                |              | 1.92      |             |
| MAX TIP SPEED  |               |        |                | EED          | 614.      |             |
| STAGES   | 1.            |        | VOL. FI        |              | 225.      |             |
| DELTA H (ACT   | 109.63        |        | HEAD C         | DEF          | 0.423     |             |
| GAMMA  | 1.43          |        | FLOW C         | DEF          | 0.156     |             |
| PRESS RATIO LT.  | (1)           |        |                |              |           |             |
|  |               |        |                |              |           |             |

## TABLE 60. — SPLIT-EXPANDER CYCLE — O/F = 6.5

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1410.8 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 20338. |
| DEL. VAC. ISP             | 480.3  |
| TOTAL ENGINE FLOW RATE    | 42.3   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.50   |
| CHAMBER/NOZZLE COOLANT DP | 628.   |
| CHAMBER/NOZZLE COOLANT DT | 1118.  |
| ETA C*                    | 0.993  |
| CHAMBER/NOZZLE Q          | 11597. |

### ENGINE STATION CONDITIONS

|                   | * FUEL | . SYSTEM C | * 2MOITIONS |                 |         |
|-------------------|--------|------------|-------------|-----------------|---------|
| STATION           | PRESS  | TEMP       | FLOH        | <b>ENTHALPY</b> | DENSITY |
| B.P. INLET        | 18.6   | 37.4       | 5.65        | -107.5          | 4.37    |
| B.P. EXIT         | 96.0   | 38.4       | 5.65        | -103.2          | 4.39    |
| PUMP INLET        | 96.0   | 38.4       | 5.65        | -103.2          | 4.39    |
| IST STAGE EXIT    | 2104.8 | 69.3       | 5.65        | 29.6            | 4.36    |
| JBV INLET         | 2065.6 | 69.7       | 2.83        | 29.6            | 4.33    |
| JBV EXIT          | 1799.7 | 71.7       | 2.83        | 29.6            | 4.15    |
| 2ND STAGE EXIT    | 3371.8 | 89.4       | 2.83        | 116.6           | 4.34    |
| PUMP EXIT         | 4602.9 | 108.3      | 2.83        | 200.4           | 4.36    |
| COOLANT INLET     | 4559.9 | 108.6      | 2.83        | 200.4           | 4.34    |
| COOLANT EXIT      | 3922.0 | 1226.8     | 2.83        | 4305.6          | 0.56    |
| TBV INLET         | 3880.1 | 1227.1     | 0.28        | 4305.6          | 0.55    |
| TBV EXIT          | 1868.7 | 1241.7     | 0.28        | 4305.6          | 0.27    |
| LOX TRB INLET     | 3880.1 | 1227.1     | 2.55        | 4305.6          | 0.55    |
| LOX TRB EXIT      | 3435.1 | 1198.1     | 2.55        | 4192.2          | 0.50    |
| H2 TRB INLET      | 3435.1 | 1198.1     | 2.55        | 4192.2          | 0.50    |
| H2 TRB EXIT       | 1968.6 | 1070.6     | 2.55        | 3708.2          | 0.33    |
| H2 TRB DIFF       | 1949.3 | 1070.7     | 2.55        | 3708.2          | 0.33    |
| H2 BST TRB IN     | 1931.4 | 1070.8     | 2.55        | 3708.2          | 0.32    |
| H2 BST TRB EXIT   | 1910.8 | 1068.3     | 2.55        | 3698.8          | 0.32    |
| H2 BST TRB DIFF   | 1906.3 | 1068.3     | 2.55        | 3698.8          | 0.32    |
| OZ BST TRB IN     | 1888.3 | 1068.4     | 2.55        | 3698.8          | 0.32    |
| OZ BST TRB EXIT   | 1878.0 | 1067.0     | 2.55        | 3693.7          | 0.32    |
| 02 BST TRB DIFF   | 1877.3 | 1067.0     | 2.55        | 3693.7          | 0.32    |
| HZ TANK PRESS     | 18.6   | 1097.7     | 0.0041      | 3753.8          | 0.0032  |
| GOX HEAT EXCH IN  | 1868.7 | 1084.3     | 2.55        | 3753.8          | 0.31    |
| GOX HEAT EXCH OUT | 1861.0 | 1083.4     | 2.55        | 3750.5          | 0.31    |
| MIXER HOT IN      | 1861.0 | 1083.4     | 2.55        | 3750.5          | 0.31    |
| MIXER COLD IN     | 1799.7 | 71.7       | 2.83        | 29.6            | 4.15    |
| MIXER OUT         | 1783.6 | 530.0      | 5.65        | 1793.9          | 0.59    |
| FSV INLET         | 1783.6 | 530.0      | 5.65        | 1793.9          | 0.59    |
| FSV EXIT          | 1741.2 | 530.2      | 5.65        | 1793.9          | 0.58    |
| CHAMBER INJ       | 1724.7 | 530.3      | 5.65        | 1793.9          | 0.57    |
| CHAMBER           | 1610.7 |            |             |                 |         |
|                   |        |            |             |                 |         |

| NOITATZ       | PRESS  | TEMP  | FLON  | ENTHALPY | DENSITY |
|---------------|--------|-------|-------|----------|---------|
| B.P. INLET    | 16.0   | 162.7 | 36.76 | 61.9     | 70.99   |
| B.P. EXIT     | 117.8  | 165.2 | 36.76 | 62.3     | 70.83   |
| PUMP INLET    | 117.8  | 165.2 | 36.76 | 62.3     | 70.83   |
| PUMP EXIT     | 2342.2 | 176.0 | 36.76 | 70.1     | 71.23   |
| 02 TANK PRESS | 16.0   | 400.0 | 0.06  | 204.7    | 0.12    |
| POSV INLET    | 2314.6 | 176.1 | 4.56  | 70.1     | 71.18   |
| POSV EXIT     | 1752.8 | 178.2 | 4.56  | 70.1     | 70.30   |
| OCV INLET     | 2314.6 | 176.1 | 32.14 | 70.1     | 71.18   |
| OCV EXIT      | 1830.4 | 177.9 | 32.14 | 70.1     | 70.43   |
| PRIMARY INJ   | 1726.9 | 178.3 | 4.54  | 70.1     | 70.26   |
| SECONDARY INJ | 1790.3 | 178.1 | 32.14 | 70.1     | 70.36   |
| CHAMBER       | 1610.7 |       |       | -        |         |

|       | VAL     | VE DATA |       |          |
|-------|---------|---------|-------|----------|
|       | ***     | *****   |       |          |
| VALVE | DELTA P | AREA    | FLON  | % BYPASS |
| JBV   | 282.    | 0.125   | 2.83  | 50.00    |
| TBV   | 2011.   | 0.018   | 0.28  | 9.82     |
| FS¥   | 42.     | 1.654   | 5.65  |          |
| POSV  | 562.    | 0.034   | 4.56  |          |
| OCV   | 484.    | 0.259   | 32.14 |          |

|          |          | ****    |        |  |
|----------|----------|---------|--------|--|
|          | # FUEL # |         | e dixo |  |
|          |          | PRIMARY | SECOND |  |
| DELP MAN | 17.15    | 12.91   | 19.96  |  |
| DELP INJ | 96.84    | 116.21  | 179.62 |  |
| AREA     | 1.14     | 0.08    | 0.43   |  |
| FLOH     | 5.65     | 4.56    | 32.14  |  |

TABLE 60. — SPLIT-EXPANDER CYCLE — O/F = 6.5 (CONTINUED)

|  |               |          | RFORMANCE DATA                          |              |                |             |
|--|---------------|----------|---|--------------|----------------|-------------|
|  |               | ******** |   |              |                |             |
| ***********  |               |          |   | BOOST PUR    |                |             |
| * H2 BOOST T   | OKRINE .      |          |   | *****        |                |             |
| ######################################                                     | 0.839         |          | EFFICIEN                                | ICY          | 0.765          |             |
| FLLICITION   | 34.           |          | HORSEPON                                | ER           | 34.            |             |
| CDEED (RPM)  | 44378.        |          | SPEED                                   | (RPM)        | 44378.         |             |
| MEAN DIA (IN)  | 1.90          |          | S SPEED                                 |              | 2980.          |             |
| EFF AREA (IN2)   |               |          | HEAD                                    | (FT)         | 2542.          |             |
| U/C (IDEAL)  |               |          | DIA.                                    | (IN)         | 2.18           |             |
| MAX TIP SPEED  |               |          | TIP SPEE                                |              | 422.           |             |
| STAGES   | 1.            |          | VOL. FLO                                |              | 578.           |             |
| DELTA H (ACT)  | 9.47          |          | HEAD COE                                | F            | 0.459          |             |
| GAMMA  | 1.39          |          | FLOW COE                                | F            | 0.198          |             |
| PRESS RATIO (T/T   | 1.01          |          |   |              |                |             |
|  |               |          |   |              | _              |             |
| *******  |               |          |   | H2 PUMP      |                |             |
| * H2 TURBINE   |               |          |   | H2 PUMP      |                |             |
| ********   |               |          |   |              |                | STAGE THREE |
|  | STAGE 1       | STAGE 2  |   |              |                | ********    |
|  | ******        | . 707    | EEE TO TENCY                            | 0 661        | 0.620          | 0.625       |
| EFFICIENCY   | 0.787         | 0.793    | EFFICIENCY<br>HORSEPOHER<br>SPEED (RPM) | 1062.        | 348.           | 335.        |
| HORSEPOWER<br>SPEED (RPM)  | 1744.         | 22010    | SPEED (RPM)<br>S SPEED                  | 122010.      | 122010.        | 122010.     |
| SPEED (RPM)  | 122010. 1     | ₹ 47     | S SPEED                                 | 713.         | 711.           | 726.        |
| MEAN DIA (IN)  | 0.21          | 0.27     | HEAD (FT)                               | 66256.       | 41945.         | 40737.      |
| EFF AREA (INL)   | 0.649         | 0.474    | DIA. (IN)                               | 3.68         | 3.02           | 3.02        |
| MAY TIP SPEED  | 1848.         | 1848.    | TIP SPEED                               | 1963.        | 1607.          | 1607.       |
| SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H | 244.          | 240.     | VOL. FLOH                               | 582.         | 292.           | 291.        |
| GAMMA (ACT)  | 1.39          | 1.39     | HEAD COEF                               | 0.553        | 0.523          | 0.507       |
| GAMMA (ACT) PRESS RATIO(T/T  | 1.33          | 1.35     | FLOW COEF                               | 0.090        | 0.089          | 0.091       |
| , ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,                                    |               |          |   |              |                |             |
| ********   | ******        |          |   | *****        |                |             |
| # 02 BOOST 1   |               |          |   | BOOST PU     |                |             |
| ********   |               |          | ****                                    | *****        | 0.753          |             |
| EFFICIENCY   | 0.844         |          | FEFTURE                                 | NCY<br>HER   | 18.            |             |
| HORSEPOWER   | 18.           |          | HUKSEPU                                 | (RPM)        | 11932          |             |
| SPEED (RPM)<br>MEAN DIA (IN)   | 11932.        |          | S SPEED                                 |              | 3336.          |             |
| MEAN DIA (IN)  | 5.21          |          | 2 2 CCD                                 | (FT)         | 207.           |             |
| EFF AREA (IN2)   | 2.02          |          | HEAD<br>DIA.                            | (IN)         | 2.44           |             |
| U/C (IDEAL)  | 0.512<br>272. |          | TIP SPE                                 |              | 127.           |             |
| MAX TIP SPEED<br>STAGES  | 1.            |          | VOL. FL                                 |              | 233.           |             |
|  |               |          | HEAD CO                                 |              | 0.412          |             |
| DELTA H (ACT)  | 1.39          |          | FLOH CO                                 | EF           | 0.213          |             |
| PRESS RATIO (T/  |               |          |   |              |                |             |
| TRESS RATES TO   |               |          |   |              |                |             |
| *******  | ***           |          |   | *******      |                |             |
| ≠ 02 TURBIN  | E *           |          |   | O2 PUMP      |                |             |
| *******  | ***           |          |   | *****        |                |             |
| <b>EFFICIENCY</b>  | 0.783         |          |   | NCY          | 0.736          |             |
| EFFICIENCY<br>HORSEPOWER   | 409.          |          | HORSEPO                                 |              | 409.           |             |
| SPEED (RPM)  | 71441.        |          |   | (RPM)        | 71441.         |             |
| MEAN DIA (IN)  | 3.47          |          | S SPEED                                 |              | 1981.<br>4496. |             |
| EFF AREA (IN2)   |               |          | HEAD                                    | (FT)<br>(IN) | 1.92           |             |
| U/C (IDEAL)  |               |          |   |              | 598.           |             |
| MAX TIP SPEED  | 1082.         |          | TIP SPE<br>VOL. FL                      |              | 232.           |             |
| STAGES   | 1.            |          | HEAD CO                                 |              | 0.405          |             |
| DELTA H (ACT)  | 113.34        |          | FLOW CO                                 | XFF          | 0.165          |             |
| GAMMA  | 1.39          | 1        | FLUM CU                                 | A.,          | *              |             |
|  | T) 1.13       |          |   |              |                |             |

### TABLE 61. — SPLIT-EXPANDER CYCLE — O/F = 7.0

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1610.8 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 20675. |
| DEL. VAC. ISP             | 477.4  |
| TOTAL ENGINE FLOW RATE    | 43.3   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 7.00   |
| CHAMBER/NOZZLE COOLANT DP | 693.   |
| CHAMBER/NOZZLE COOLANT DT | 1211.  |
| ETA C#                    | 0.988  |
| CHAMBER/NOZZLE Q          | 12005. |

# 

|                   | * FUEL | - ZAZIEM CO | * SMOTTEGMS |          |         |
|-------------------|--------|-------------|-------------|----------|---------|
| STATION           | PRESS  | TEMP        | FLOH        | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4        | 5.42        | -107.5   | 4.37    |
| B.P. EXIT         | 93.3   | 38.4        | 5.42        | -103.4   | 4.39    |
| PUMP INLET        | 93.3   | 38.4        | 5.42        | -103.4   | 4.39    |
| 1ST STAGE EXIT    | 2071.6 | 68.9        | 5.42        | 27.7     | 4.35    |
| JBV INLET         | 2035.6 | 69.2        | 2.71        | 27.7     | 4.33    |
| JBA EXIL          | 1794.4 | 71.1        | 2.71        | 27.7     | 4.16    |
| 2ND STAGE EXIT    | 3318.8 | 88.7        | 2.71        | 113.5    | 4.34    |
| PUMP EXIT         | 4529.9 | 107.5       | 2.71        | 196.2    | 4.35    |
| COOLANT INLET     | 4490.4 | 107.8       | 2.71        | 196.2    | 4.34    |
| COOLANT EXIT      | 3797.5 | 1319.3      | 2.71        | 4628.2   | 0.50    |
| TBV INLET         | 3754.8 | 1319.6      | 0.35        | 4628.2   | 0.50    |
| TBV EXIT          | 1859.1 | 1333.6      | 0.35        | 4628.2   | 0.25    |
| LOX TRB INLET     | 3754.8 | 1319.6      | 2.36        | 4628.2   | 0.50    |
| LOX TRB EXIT      | 3331.6 | 1289.4      | 2.36        | 4510.9   | 0.46    |
| H2 TRB INLET      | 3331.6 | 1289.4      | 2.36        | 4510.9   | 0.46    |
| H2 TRB EXIT       | 1952.4 | 1158.8      | 2.36        | 4016.3   | 0.30    |
| H2 TRB DIFF       | 1934.3 | 1158.9      | 2.36        | 4016.3   | 0.30    |
| H2 BST TRB IN     | 1917.6 | 1159.0      | 2.36        | 4016.3   | 0.30    |
| H2 BST TRB EXIT   | 1898.3 | 1156.4      | 2.36        | 4006.8   | 0.30    |
| H2 BST TRB DIFF   | 1894.2 | 1156.5      | 2.36        | 4006.8   | 0.29    |
| O2 BST TRB IN     | 1877.9 | 1156.6      | 2.36        | 4006.8   | 0.29    |
| O2 BST TRB EXIT   | 1867.8 | 1155.2      | 2.36        | 4001.7   | 0.29    |
| O2 BST TRB DIFF   | 1867.1 | 1155.2      | 2.36        | 4001.7   | 0.29    |
| H2 TANK PRESS     | 18.6   | 1192.1      | 0.0036      | 4082.7   | 0.0029  |
| GOX HEAT EXCH IN  | 1859.1 | 1178.3      | 2.36        | 4082.7   | 0.28    |
| GOX HEAT EXCH OUT | 1851.9 | 1177.3      | 2.36        | 4079.0   | 0.28    |
| MIXER HOT IN      | 1851.9 | 1177.3      | 2.36        | 4079.0   | 0.28    |
| MIXER COLD IN     | 1794.4 | 71.1        | 2.71        | 27.7     | 4.16    |
| MIXER OUT         | 1779.6 | 562.8       | 5.41        | 1913.3   | 0.56    |
| FSV INLET         | 1779.6 | 562.8       | 5.41        | 1913.3   | 0.56    |
| FSV EXIT          | 1738.2 | 563.0       | 5.41        | 1913.3   | 0.54    |
| CHAMBER INJ       | 1722.1 | 563.1       | 5.41        | 1913.3   | 0.54    |
| CHAMBER           | 1610.8 |             |             |          |         |
|                   |        |             |             |          |         |

| * OXY  | GEN SYSTEM  | CONDITIONS  | S •  |   |
|--------|---|---|--|---|
| PRESS  | TEMP  | FLON  | ENTHALPY   | DENSITY   |
| 16.0   | 162.7   | 37.96   | 61.9   | 70.99   |
| 104.1  | 165.2   | 37.96   | 62.2   | 70.82   |
| 104.1  | 165.2   | 37.96   | 62.2   | 70.82   |
| 2149.2 | 175.3   | 37.96   | 69.5   | 71.16   |
| 16.0   | 400.0   | 0.06  | 204.7  | 0.12  |
| 2119.8 | 175.4   | 3.88  | 69.5   | 71.12   |
| 1712.8 | 176.9   | 3.88  | 69.5   | 70.48   |
| 2119.8 | 175.4   | 34.02   | 69.5   | 71.12   |
| 1855.9 | 176.4   | 34.02   | 69.5   | 70.71   |
| 1694.0 | 177.0   | 3.88  | 69.5   | 70.45   |
| 1811.1 | 176.5   | 34.02   | 69.5   | 70.64   |
| 1610.1 |   |   |  |   |
|        | PRESS<br>16.0<br>104.1<br>104.1<br>2149.2<br>16.0<br>2119.8<br>1712.8<br>2119.8<br>1855.9<br>1694.0 | PRESS TEMP 16.0 162.7 104.1 165.2 104.1 165.2 2149.2 175.3 16.0 400.0 2119.8 175.4 1712.8 176.9 2119.8 175.4 1855.9 176.4 1894.0 177.0 1811.1 176.5 | PRESS TEMP FLOW 16.0 162.7 37.96 104.1 165.2 37.96 104.1 165.2 37.96 2149.2 175.3 37.96 16.0 400.0 0.06 2119.8 175.4 3.88 2119.8 175.4 3.88 2119.8 175.4 34.02 1855.9 176.4 34.02 1855.9 176.4 34.02 | 16.0 162.7 37.96 61.9<br>104.1 165.2 37.96 62.2<br>104.1 165.2 37.96 62.2<br>2149.2 175.3 37.96 69.5<br>16.0 400.0 0.06 204.7<br>2119.8 175.4 3.88 69.5<br>1712.8 176.9 3.88 69.5<br>2119.8 175.4 34.02 69.5<br>1855.9 176.4 34.02 69.5<br>1895.0 177.0 3.88 69.5<br>1894.0 177.0 3.88 69.5 |

|    | VAL   | VE DATA |       |          |
|----|-------|---------|-------|----------|
|    | # H H | *****   |       |          |
| DE | LTA P | AREA    | FLOM  | & BYPASS |
|    | 256.  | 0.125   | 2.71  | 50.00    |
|    | 1896. | 0.024   | 0.35  | 12.93    |
|    | 41.   | 1.654   | 5.41  |          |
|    | 407.  | 0.034   | 3.88  |          |
|    | 264.  | 0.371   | 34.02 |          |

### INJECTOR DATA

|          | • FUEL • | •       | ■ C1XO |
|----------|----------|---------|--------|
|          |          | PRIMARY | SECOND |
| DELP MAN | 16.70    | 9.32    | 22.27  |
| DELP INJ | 94.69    | 83.90   | 200.43 |
| AREA     | 1.14     | 0.08    | 0.43   |
| FLOH     | 5.41     | 3.88    | 34.02  |

VALVE JBV TBV FSV POSV OCV

TABLE 61. — SPLIT-EXPANDER CYCLE — O/F = 7.0 (CONTINUED)

|  |            |           | *********                            |                   |                        |             |
|--|------------|-----------|--------------------------------------|-------------------|------------------------|-------------|
|  | * TURBOMAC | CHINERY P | ERFORMANCE DATA                      | Α =               |                        |             |
|  | ******     | ********  | *******                              |                   |                        |             |
| *******  | *******    |           |                                      | ********          |                        |             |
| # H2 BOOST T   | URBINE #   |           | ■ H2                                 | BOOST PUR         | ₽ *                    |             |
| *******  | *******    |           |                                      | ******            |                        |             |
| EFF1CTENCY   | 0.826      |           |                                      | NCY               | 0.764                  |             |
| HORSEPOHER   | 32.        |           | HORSEPO                              | HER               | 32.                    |             |
| SPEED (RPM)  |            |           | SPEED                                | (RPM)             | 43200.                 |             |
| MEAN DIA (IN)  |            |           | S SPEED                              |                   | 2915.                  |             |
| EFF AREA (IN2)   |            |           | HEAD                                 | (FT)              | 2455.                  |             |
| U/C (IDEAL)  |            |           | DIA.                                 | (IN)              | 2.18                   |             |
| MAX TIP SPEED  | 358.       |           | TIP SPE                              | ED                | 411.                   |             |
| STAGES   | 1.         |           | VOL. FL                              |                   | 554.                   |             |
| DELTA H (ACT)  |            |           | HEAD CO                              |                   | 0.468                  |             |
| GAMMA (ACT)  | 1.38       |           | FLOW CO                              |                   | 0.195                  |             |
| PRESS RATIO (T/)   |            |           | 1 2011 301                           |                   |                        |             |
| ******   |            |           |                                      | * # # * * * * * * |                        |             |
| * H2 TURBINE   |            |           |                                      | H2 PUMP           |                        |             |
|  |            |           |                                      | *****             |                        |             |
| *******  |            | STAGE 2   |                                      |                   |                        | STAGE THREE |
|  |            | SIAGE 2   |                                      |                   |                        | *******     |
| FEETOTENCY   | 0 777      | 0.792     | EFFICIENCY<br>HORSEPOWER             | 0.640             | 0.619                  | 0.624       |
| EFFICIENCY   | 0.775      | 0.762     | UNDER DOME D                         | 1005              | 329.                   | 317.        |
| HORSEPOHER   | 1650.      | 1650.     | HORSEPOWER<br>SPEED (RPM)<br>S SPEED | 120203            | 120203.                | 120203.     |
| SPEED (RPM)  |            |           | SEED INCH!                           | 696               | 694.                   | 709.        |
| MEAN DIA (IN)  | 3.47       | 3.47      | 5 SPEED (ET)                         | 45297             | 61325                  | 40126.      |
| HEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H | 0.21       | 0.27      | HEAU (FI)                            | 7 40              | 3.02                   | 3.02        |
| U/C (IDEAL)  | 0.452      | 0.460     | DIA. (IN)                            | 1076              | 1507                   | 1583.       |
| MAX TIP SPEED  | 1821.      | 1821.     | LIN PAFER                            | 1734.             | 200                    | 279.        |
| DELTA H  | 251.       | 244.      | VOL. FLUM                            | 220.              | 1583.<br>280.<br>0.530 | 0.515       |
| GAMMA (ACT) PRESS RATIO(T/T                                    | 1.38       | 1.38      | HEAD COEF                            | 0.087             | 0.550                  |             |
| PRESS RATIO(T/T  | 1.33       | 1.35      | FLOW COEF                            | 0.087             | 0.007                  | 0.000       |
| ******   |            |           |                                      |                   |                        |             |
| # 02 BOOST   |            |           |                                      | BOOST PU          |                        |             |
| *******  |            |           |                                      |                   |                        |             |
| EFFICIENCY   | 0.833      |           |                                      | NCY               | 0.726<br>17.           |             |
| HORSEPOWER   | 17.        |           | HORSEPO                              |                   |                        |             |
| SPEED (RPM) MEAN DIA (IN)                                      | 11659.     |           |                                      | (RPM)             | 11659.                 |             |
| MEAN DIA (IN)  |            |           | S SPEED                              |                   | 3691.                  |             |
| EFF AREA (IN2)   |            |           | HEAD                                 | (FT)<br>(IN)      | 179.                   |             |
| U/C (IDEAL)  |            |           |                                      |                   | 2.44                   |             |
| MAX TIP SPEED  | 265.       |           | TIP SPE                              |                   | 124.                   |             |
| STAGES   | 1.         |           | VOL. FL                              |                   | 241.                   |             |
| DELTA H (ACT)  | 5.11       |           | HEAD CO                              | EF                | 0.373                  |             |
| GAMMA  | 1.38       |           | FLOW CO                              | EF                | 0.225                  |             |
| PRESS RATIO (T/  | 1, 1.01    |           |                                      |                   |                        |             |
| *****  |            |           |                                      | ******            |                        |             |
| # O2 TURBIN  |            |           |                                      | 02 PUMP =         |                        |             |
| ********   |            |           |                                      |                   |                        |             |
| EFFICIENCY   | 0.767      |           | EFF1C1E                              | NCY               | 0.729                  |             |
| HORSEPOHER   | 391.       |           | HORSEPO                              | IMER              | 391.                   |             |
| SPEED (RPM)  |            |           |                                      | (RPM)             | 70123.                 |             |
| MEAN DIA (IN)  |            |           | S SPEED                              |                   | 2103.                  |             |
| EFF AREA (IN2)   |            |           | HEAD                                 | (FT)              | 4137.                  |             |
| U/C (IDEAL)  |            |           | DIA.                                 | (IN)              | 1.92                   |             |
| MAX TIP SPEED  |            |           | TIP SPE                              |                   | 587.                   |             |
| STAGES   | 1.         |           | VÓL. FL                              |                   | 239.                   |             |
| DELTA H (ACT)  | 117.33     | :         | HEAD CO                              |                   | 0.387                  |             |
| GAMMA  | 1.38       | 1         | FLOW CO                              | ŒF                | 0.174                  |             |
| PRESS RATIO (T/  | T) 1.13    | •         |                                      |                   |                        |             |
|  |            |           |                                      |                   |                        |             |

### TABLE 62. — SPLIT-EXPANDER CYCLE — O/F = 12.0

### ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1250.0 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 15884. |
| DEL. VAC. ISP             | 396.3  |
| TOTAL ENGINE FLOW RATE    | 40.1   |
| THROAT AREA               | 6.071  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 12.00  |
| CHAMBER/NOZZLE COOLANT DP | 455.   |
| CHAMBER/NOZZLE COOLANT DT | 726.   |
| ETA C*                    | 0.980  |
| CHAMBER/NOZZLE Q          | 8431.  |

#### ENGINE STATION CONDITIONS \*\*\*\*\*\*\*\*\*\*\*\*

|                   | * FUEL | SYSTEM CO | NDITIONS # |          |         |
|-------------------|--------|-----------|------------|----------|---------|
| STATION           | PRESS  | TEMP      | FLOW       | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4      | 3.09       | -107.5   | 4.37    |
| B.P. EXIT         | 93.6   | 38.9      | 3.09       | -102.3   | 4.37    |
| PUMP INLET        | 93.6   | 38.9      | 3.09       | -102.3   | 4.37    |
| IST STAGE EXIT    | 2053.3 | 76.4      | 3.09       | 48.7     | 4.14    |
| JBV INLET         | 2053.5 | 76.4      | 0.00       | 48.7     | 4.14    |
| JBV EXIT          | 1497.9 | 79.3      | 0.00       | 48.7     | 3.71    |
| 2ND STAGE EXIT    | 2924.6 | 92.0      | 3.09       | 114.3    | 4.12    |
| PUMP EXIT         | 3762.9 | 106.9     | 3.09       | 177.3    | 4.11    |
| COOLANT INLET     | 3708.6 | 107.3     | 3.09       | 177.3    | 4.09    |
| COOLANT EXIT      | 3253.7 | 833.8     | 3.09       | 2909.1   | 0.67    |
| TBV INLET         | 3212.2 | 834.1     | 0.52       | 2909.1   | 0.66    |
| TBV EXIT          | 1568.7 | 844.6     | 0.52       | 2909.1   | 0.33    |
| LOX TRB INLET     | 3212.2 | 834.1     | 2.56       | 2909.L   | 0.66    |
| LOX TRB EXIT      | 2844.1 | 814.2     | 2.56       | 2830.0   | 0.61    |
| H2 TRB INLET      | 2844.1 | 814.2     | 2.56       | 2830.0   | 0.61    |
| H2 TRB EXIT       | 1650.5 | 726.3     | 2.56       | 2493.2   | 0.41    |
| H2 TRB DIFF       | 1634.7 | 726.4     | 2.56       | 2493.2   | 0.40    |
| H2 BST TRB IN     | 1620.0 | 726.5     | 2.56       | 2493.2   | 0.40    |
| H2 BST TRB EXIT   | 1603.1 | 724.8     | 2.56       | 2486.9   | 0.40    |
| H2 BST TRB DIFF   | 1599.5 | 724.8     | 2.56       | 2486.9   | 0.40    |
| OZ BST TRB IN     | 1585.1 | 724.9     | 2.56       | 2486.9   | 0.39    |
| O2 BST TRB EXIT   | 1576.3 | 724.0     | 2.56       | 2483.4   | 0.39    |
| O2 BST TRB DIFF   | 1575.7 | 724.0     | 2.56       | 2483.4   | 0.39    |
| H2 TANK PRESS     | 18.6   | 753.8     | 0.0033     | 2555.7   | 0.0046  |
| GOX HEAT EXCH IN  | 1568.7 | 744.5     | 2.56       | 2555.7   | 0.38    |
| GOX HEAT EXCH OUT | 1562.2 | 743.6     | 2.56       | 2552.3   | 0.38    |
| MIXER HOT IN      | 1562.2 | 743.6     | 2.56       | 2552.3   | 0.38    |
| MIXER COLD IN     | 1497.9 | 79.3      | 0.00       | 48.7     | 3.71    |
| MIXER DUT         | 1497.9 | 744.0     | 3.08       | 2552.3   | 0.36    |
| FSV INLET         | 1497.9 | 744.0     | 3.08       | 2552.3   | 0.36    |
| FSV EXIT          | 1320.1 | 745.1     | 3.08       | 2552.3   | 0.32    |
| CHAMBER INJ       | 1311.3 | 745.1     | 3.08       | 2552.3   | 0.32    |
| CHAMBER           | 1249.9 |           |            |          |         |
|                   |        |           |            |          |         |

|               | * OXY  | GEN SYSTEM | CONDITIONS | S #      |         |
|---------------|--------|------------|------------|----------|---------|
| STATION       | PRESS  | TEMP       | FLOW       | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7      | 37.06      | 61.9     | 70.99   |
| B.P. EXIT     | 82.2   | 165.1      | 37.06      | 62.2     | 70.82   |
| PUMP INLET    | 82.2   | 165.1      | 37.06      | 62.2     | 70.82   |
| PUMP EXIT     | 1569.4 | 172.9      | 37.06      | 67.6     | 71.01   |
| 02 TANK PRESS | 16.0   | 400.0      | 0.06       | 204.7    | 0.12    |
| POSV INLET    | 1541.3 | 173.0      | 2.93       | 67.6     | 70.97   |
| POSV EXIT     | 1308.1 | 173.9      | 2.93       | 67.6     | 70.59   |
| OCV INLET     | 1541.3 | 173.0      | 34.06      | 67.6     | 70.97   |
| OCV EXIT      | 1495.2 | 173.2      | 34.06      | 67.6     | 70.89   |
| PRIMARY INJ   | 1297.4 | 173.9      | 2.93       | 67.6     | 70.57   |
| SECONDARY INJ | 1450.4 | 173.3      | 34.06      | 67.6     | 70.82   |
| CHAMBER       | 1249.6 |            |            |          |         |

|         | VAL     | VE DATA |       |          |  |  |  |  |  |  |
|---------|---------|---------|-------|----------|--|--|--|--|--|--|
| 相非共同相对的 |         |         |       |          |  |  |  |  |  |  |
| VALVE   | DELTA P | AREA    | FLOM  | % BYPASS |  |  |  |  |  |  |
| JBV     | 555.    | 0.000   | 0.00  | 0.00     |  |  |  |  |  |  |
| TBV     | 1643.   | 0.033   | 0.52  | 16.98    |  |  |  |  |  |  |
| FSV     | 178.    | 0.600   | 3.08  |          |  |  |  |  |  |  |
| POSV    | 233.    | 0.034   | 2.93  |          |  |  |  |  |  |  |
| OCV     | 46.     | 0.193   | 34.06 |          |  |  |  |  |  |  |

### INJECTOR DATA

\* FUEL \* DELP MAN 9.17 DELP INJ 52.07 AREA 1.16 52.07 1.14 3.08 FLOH

TABLE 62. — SPLIT-EXPANDER CYCLE — O/F = 12.0 (CONTINUED)

|                                     |                                |           | *********   |             |                |             |  |
|-------------------------------------|--------------------------------|-----------|---|-------------|----------------|-------------|--|
|                                     | * TURBOMA                      | CHINERY P | ERFORMANCE DATA                                   | A #         |                |             |  |
|                                     | ******                         |           | **********  | * * *       |                |             |  |
| ********                            | ******                         |           | *********   |             |                |             |  |
| * H2 BOOST                          | TURBINE *                      |           | * H2  | BOOST PU    | MP *           |             |  |
| ********                            | ******                         |           | ***   |             | ***            |             |  |
| EFFICIENCY                          | 0.844                          |           | FFF1C1F1  | NCY         | 0.608          |             |  |
| HORSEPOWER                          | 23.                            |           | HORSEPO   | JFR         | 23.            |             |  |
| SPEED (RPM)                         |                                |           | SPEED   |             | 36541.         |             |  |
| MEAN DIA (IN)                       |                                |           | S SPEED   |             | 1856.          |             |  |
|                                     |                                |           |   |             |                |             |  |
| EFF AREA (IN2)                      |                                |           | HEAD  | (FT)        | 2472.          |             |  |
| U/C (IDEAL)                         |                                |           | DIA.  |             | 2.18           |             |  |
| MAX TIP SPEED                       | 302.                           |           | TIP SPE   |             | 347.           |             |  |
| STAGES                              | 1.                             |           | VOL. FLO  | OH-         | 317.           |             |  |
| DELTA H (ACT)                       | 6.30                           |           | HEAD CO   | EF.         | 0.659          |             |  |
| GAMMA                               | 1.44                           |           | FLOH CO   | EF          | 0.132          |             |  |
| PRESS RATIO (T/                     | T) 1.01                        |           |   |             |                |             |  |
|                                     |                                |           |   |             |                |             |  |
| *******                             | ***                            |           |   | *******     | *              |             |  |
| * H2 TURBIN                         | E .                            |           |   | H2 PUMP     |                |             |  |
| ********                            |                                |           |   | *****       |                |             |  |
|                                     |                                | STAGE 2   |   |             |                | STAGE THREE |  |
|                                     |                                | STROC 2   |   |             |                | ********    |  |
| EFFICIENCY                          |                                |           |   | 0.572       |                |             |  |
|                                     | 0.827                          | 0.836     | EFFICIENCY  | 659.        |                |             |  |
| HORSEPOWER                          | 1221.                          |           | HORSEPOHER  |             |                |             |  |
| SPEED (RPM)                         |                                | 113796.   | SPEED (RPM) S SPEED HEAD (FT) DIA. (IN) TIP SPEED | 113/96.     | 113796.        | 113/96.     |  |
| MEAN DIA (IN)                       | 3.47                           | 3.47      | S SPEED   | 499.        | 907.           | 932.        |  |
| EFF AREA (IN2)                      | 3.47<br>0.21<br>0.534<br>1724. | 0.27      | HEAD (FT)   | 67185.      | 30401.         | 29329.      |  |
| U/C (IDEAL)                         | 0.534                          | 0.548     | DIA. (IN)   | 3.68        | 3.02           | 3.02        |  |
| MAX TIP SPEED                       | 1724.                          | 1724.     | TIP SPEED   | 1831.       | 1499.          | 1499.       |  |
| DELTA H                             | 172.                           | 165.      | VOL. FLOW   | 335.        | 336.           | 337.        |  |
| GAMMA (ACT)                         | 1.44                           | 1.44      | HEAD COEF   | 0.645       | 0.435          | 0.420       |  |
| DELTA H GAMMA (ACT) PRESS RATIO(T/T | 1.33                           | 1.35      | FLOW COEF   | 0.055       | 0.435<br>0.110 | 0.112       |  |
|                                     |                                |           |   |             |                |             |  |
| ********                            | ******                         |           | ****  | ******      | ***            |             |  |
| * 02 BOOST                          | * JURBINE *                    |           | * 02  | BOOST PU    | MP #           |             |  |
| ********                            |                                |           | ****  | ******      |                |             |  |
| EFF1CIENCY                          | 0.878                          |           | EFF1C1E   | <b>√</b> CY | 0.715          |             |  |
| HORSEPOWER                          | 13.                            |           | HORSEPO   | MFR.        | 13.            |             |  |
| SPEED (RPM)                         |                                |           | SPEED   | (RPM)       | 10741.         |             |  |
| MEAN DIA (IN)                       |                                |           | S SPEED   |             | 4163.          |             |  |
| EFF AREA (IN2)                      |                                |           |   | (FT)        | 135.           |             |  |
|                                     |                                |           |   |             | 2.44           |             |  |
| U/C (IDEAL)                         |                                |           |   | (IN)        |                |             |  |
| MAX TIP SPEED                       |                                |           | TIP SPEE  |             | 115.           |             |  |
| STAGES                              | 1.                             |           | VOL. FLO  |             | 235.           |             |  |
| DELTA H (ACT)                       |                                |           | HEAD COE  |             | 0.330          |             |  |
| GAMMA                               | 1.44                           |           | FLOW COE  | EF .        | 0.238          |             |  |
| PRESS RATIO (T/                     | T) 1.01                        |           |   |             |                |             |  |
|                                     |                                |           |   |             |                |             |  |
| ********                            | ***                            |           |   | ******      |                |             |  |
| * 02 TURBIN                         | Ε *                            |           |   | 02 PUMP #   |                |             |  |
| *******                             | ***                            |           | ***   |             |                |             |  |
| EFFICIENCY                          | 0.807                          |           | EFFICIEN  | 4CY         | 0.708          |             |  |
| HORSEPOWER                          | 287.                           |           | HORSEPOR  | <b>√</b> ER | 287.           |             |  |
| SPEED (RPM)                         | 62881.                         |           | SPEED   | (RPM)       | 62881.         |             |  |
| MEAN DIA (IN)                       |                                |           | S SPEED   |             | 2365.          |             |  |
| EFF AREA (IN2)                      |                                |           | WEAD  | (FT)        | 3015.          |             |  |
| U/C (IDEAL)                         |                                |           | DIA.  | (IN)        | 1.92           |             |  |
| MAX TIP SPEED                       | 953.                           |           | TIP SPEE  | TD          | 526.           |             |  |
|                                     |                                |           | VOL. FLO  |             | 234.           |             |  |
| STAGES                              | 1.                             |           |   |             | 0,350          |             |  |
| DELTA H (ACT)                       | 79.16                          |           | HEAD COE  |             |                |             |  |
| GAMMA                               | 1.44                           |           | FLOW COE  | .r          | 0.190          |             |  |
| PRESS RATIO (T/                     | 1, 1.13                        |           |   |             |                |             |  |
|                                     |                                |           |   |             |                |             |  |

## TABLE 63. - FULL-EXPANDER CYCLE WITH REGENERATION - O/F = 5.0

|      |   | E | N | G | Į | N | Ε |   | P | E | R | F | 0 | R | ĸ | ٨ | N | a | E | - ( | P | V | 1 | ď | E | Ŧ | E | R | s |   |  |
|------|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|-----|---|---|---|---|---|---|---|---|---|---|--|
| <br> | _ |   |   | _ |   | _ | _ | _ | _ | _ | _ | _ | _ |   | _ | _ |   | _ |   | _   | _ |   |   |   |   | _ | _ | _ | _ | _ |  |

| CHAMBER PRESSURE          | 1497.1 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 16436. |
| DEL. VAC. ISP             | 477.1  |
| TOTAL ENGINE FLOW RATE    | 34.4   |
| THROAT AREA               | 5.547  |
| NOZZLE AREA RATIO         | 1900.0 |
| ENGINE MIXTURE RATIO      | 5.00   |
| CHAMBER/NOZZLE COOLANT DP | 772.   |
| CHAMBER/NOZZLE COOLANT DT | 385.   |
| ETA CH                    | 0.993  |
| CHAMBER / NO ZZLE Q       | 8653.  |

## ENGINE STATION CONDITIONS

|                   | * FUEL | SYSTEM CO  | * ZMOITIONS |          |         |
|-------------------|--------|------------|-------------|----------|---------|
| STATION           | PRESS  | TEMP       | FLON        | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4       | 5.75        | -107.5   | 4.37    |
| B.P. EXIT         | 95.1   | 38.4       | 5.75        | -103.3   | 4.39    |
| PUMP INLET        | 95.1   | 38.4       | 5.75        | -103.3   | 4.39    |
| IST STAGE EXIT    | 1696.7 | 51.4       | 5.75        | -2.2     | 4.41    |
| 2ND STAGE EXIT    | 3281.1 | 83.3       | 5.75        | 97.1     | 4.45    |
| PUMP EXIT         | 4852.5 | 104.2      | 5.75        | 194.6    | 4.50    |
| COLD REGEN IN     | 4801.2 | 104.7      | 5.75        | 194.6    | 4.48    |
| COLD REGEN EX     | 4748.3 | 227.5      | 5.75        | 631.7    | 2.79    |
| COOLANT INLET     | 4748.3 | 227.5      | 5.75        | 631.7    | 2.78    |
| COOLANT EXIT      | 3976.7 | 612.3      | 5.75        | 2136.6   | 1.06    |
| TBV INLET         | 3938.9 | 612.5      | 0.06        | 2136.6   | 1.05    |
| TBV EXIT          | 1736.3 | 624.9      | 0.86        | 2136.6   | 0.49    |
| LOX TRB INLET     | 3938.9 | 612.5      | 5.69        | 2136.6   | 1.05    |
| LOX TRB EXIT      | 3570.4 | 600.B      | 5.69        | 2085.7   | 0.98    |
| H2 TRB [NLET      | 3570.4 | 600.8      | 5.69        | 2085.7   | 0.98    |
| H2 TRB EXIT       | 1859.4 | 527.2      | 5.69        | 1784.8   | 0.61    |
| H2 TRB DIFF       | 1829.2 | 527.3      | 5.69        | 1784.8   | 0.61    |
| H2 BST TRB IN     | 1808.7 | 527.4      | 5.69        | 1784.8   | 0.60    |
| H2 BST TRB EXIT   | 1789.7 | 526.3      | 5.69        | 1780.5   | 0.59    |
| H2 BST TRB DIFF   | 1776.4 | 526.4      | 5.69        | 1780.5   | 0.59    |
| O2 BST TRB IN     | 1756.4 | 526.5      | 5.69        | 1780.5   | 0.58    |
| O2 BST TRB EXIT   | 1747.5 | 525.9      | 5.69        | 1778.3   | 0.58    |
| O2 BST TRB DIFF   | 1746.1 | 525.9      | 5.69        | 1778.3   | 0.58    |
| H2 TANK PRESS     | 18.6   | 533.9      | 0.0086      | 1781.8   | 0.0066  |
| GOX HEAT EXCH IN  | 1736.3 | 526.9      | 5.69        | 1781.8   | 0.58    |
| GOK HEAT EXCH OUT | 1727.4 | 526.6      | 5.69        | 1780.7   | 0.57    |
| HOT REGEN IN      | 1727.4 | 526.6      | 5.69        | 1780.7   | 0.57    |
| HOT REGEN EX      | 1675.0 | 407.9      | 5.69        | 1339.2   | 0.71    |
| FSV INLET         | 1675.0 | 407.9      | 5.74        | 1339.1   | 0.71    |
| FSV EXIT          | 1631.5 | 408.0      | 5.74        | 1339.1   | 0.70    |
| CHAMBER INJ       | 1614.5 | 408.1      | 5.74        | 1339.1   | 0.69    |
| CHAMBER           | 1496.5 |            |             |          |         |
|                   | * OXY  | GEN SYSTEM | CONDITIONS  | 5 •      |         |

|               | * OXY  | ŒN SYSTEM | CONDITION | S •      |         |
|---------------|--------|-----------|-----------|----------|---------|
| STATION       | PRESS  | TEMP      | FLOM      | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7     | 28.76     | 61.9     | 70.99   |
| B.P. EXIT     | 141.8  | 165.4     | 28.76     | 62.4     | 70.83   |
| PUMP INLET    | 141.8  | 165.4     | 28.76     | 62.4     | 70.83   |
| PUMP EXIT     | 2965.7 | 179.4     | 28.76     | 72.5     | 71.28   |
| 02 TANK PRESS | 16.0   | 400.0     | 0.05      | 204.7    | 0.12    |
| POSV INLET    | 2947.0 | 179.5     | 6.21      | 72.5     | 71.26   |
| POSV EXIT     | 1792.8 | 184.0     | 6.21      | 72.5     | 69.45   |
| OCV INLET     | 2947.0 | 179.5     | 22.50     | 72.5     | 71.26   |
| OCV EXIT      | 1618.5 | 184.7     | 22.50     | 72.5     | 69.16   |
| PRIMARY INJ   | 1738.8 | 184.2     | 6.21      | 72.5     | 69.36   |
| SECONDARY INJ | 1596.3 | 184.8     | 22.50     | 72.5     | 69.12   |
| CHAMBER       | 1497.1 |           |           |          |         |

|             | A:T     | VE DATA |       |          |
|-------------|---------|---------|-------|----------|
|             | • • •   | *****   |       |          |
| VALVE       | DELTA P | AREA    | FLON  | % BYPASS |
| TBV         | 2203.   | 0.003   | 0.06  | 1.00     |
| FSV         | 44.     | 1.502   | 5.74  |          |
| POSV        | 1154.   | 0.032   | 6.21  |          |
| oc <b>v</b> | 1329.   | 0.109   | 22.50 |          |

|          | * FUEL * | * C:XO * |        |  |  |  |
|----------|----------|----------|--------|--|--|--|
|          |          | FRIMARY  | SECOND |  |  |  |
| DELP MAN | 17.63    | 20.85    | 11.03  |  |  |  |
| DELP INJ | 99.78    | 241.70   | 99.21  |  |  |  |
| AREA     | 1.03     | 0.07     | 0.41   |  |  |  |
| FLOW     | 5.74     | 5.21     | 22.50  |  |  |  |

TABLE 63. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 5.0 (CONTINUED)

|                           | *******         |                 | ******  |           |                                |                |
|---------------------------|-----------------|-----------------|---|-----------|--------------------------------|----------------|
|                           |                 |                 | ERFORMANCE DATA                                   |           |                                |                |
|                           |                 | ******          | ********  |           |                                |                |
| ********                  |                 |                 |   | ********  |                                |                |
| # H2 BOOST                |                 |                 |   | BOOST PUP |                                |                |
| EFFICIENCY                | 0.779           |                 | FFFICIEN  |           | 0.765                          |                |
| HORSEPOWER                | 34.             |                 | HORSEPON  |           | 34.                            |                |
| SPEED (RPM)               |                 |                 | SPEED   | (RPH)     | 44528.                         |                |
| MEAN DIA (IN)             |                 |                 | S SPEED   |           | 3041.                          |                |
| EFF AREA (IN2)            |                 |                 | HEAD  |           | 2514.                          |                |
| U/C (IDEAL)               |                 |                 |   | (IN)      | 2.18                           |                |
| MAX TIP SPEED             |                 |                 | TIP SPEE  |           | 423.                           |                |
| STAGES                    | 1.              |                 | VOL. FLO<br>HEAD COE                              |           | 588.<br>0.451                  |                |
| DELTA H (ACT)             | 1.38            |                 | FLOW COE  |           | 0.201                          |                |
| GAMMA PRESS RATIO (T/     |                 |                 | TEOR COL  |           |                                |                |
| PRESS RATIO (1)           | 1, 1.01         |                 |   |           |                                |                |
| ********                  | ***             |                 | * *   | ******    | •                              |                |
| # H2 TURBIN               | Æ ¥             |                 |   | H2 PUMP   |                                |                |
| *******                   |                 |                 |   | ******    |                                |                |
|                           | STAGE 1 :       |                 |   |           |                                | STAGE THREE    |
|                           | *****           |                 | FEETOTENCY  | V 444     | 0.666                          | 0.667          |
| EFF ICIENCY               | 0.853           | 0.838           | EFFICIENCY<br>HORSEPOHER<br>SPEED (RPM)           | 823.      | 808.                           | 793.           |
| HOKSENOMER                | 118750 1        | 18750.          | SPEED (RPM)                                       | 118750.   | 118750.                        | 118750.        |
| MEAN DIA (IM)             | 2.86            | 7.86            | S SPEED   | 830.      | 837.                           | 843.           |
| FEF AREA (IN2)            | 0.31            | 0.40            | HEAD (FT)   | 5.2380    | 51514.                         | 50562.         |
| U/C (IDEAL)               | 0.503           | 0.491           | DIA. (IN)   | 3.44      | 3.44                           | 3.44           |
| MAX TIP SPEED             | 1484.           | 1484.           | HEAD (FT) DIA. (IN) TIP SPEED VOL. FLOW HEAD COEF | 1785.     | 1785.                          | 1785.          |
| DELTA H                   | 148.            | 153.            | VOL. FLOW   | 585.      | 581.                           | 573.           |
| GAMMA (ACT)               | 1.38            | 1.38            | HEAD COEF   | 0.529     | 3.44<br>1785.<br>581.<br>0.520 | 0.510<br>0.101 |
| PRESS RATIO(T/T           | 1.34            | 1.37            | FLOW COEF   | 0.100     | 0.100                          | 0.101          |
| ******                    |                 |                 |   | ******    |                                |                |
| # 02 BOOST                |                 |                 |   | BOOST PU  |                                |                |
| *********                 |                 |                 |   | ******    |                                |                |
| EFFICIENCY                | 0.861           |                 | EFFICIEN  | ICY .     | 0.728                          |                |
| HORSEPOHER                | 18.             |                 | HOR SEP OF  |           | 18.                            |                |
| SPEED (RPM) MEAN DIA (IN) | 11559.          |                 |   | (RPM)     |                                |                |
| MEAN DIA (IN)             | 3.69            |                 | S SPEED   |           | 2439.                          |                |
| EFF AREA (IN2)            |                 |                 | HEAD<br>DIA.                                      | (FT)      | 256.<br>2.44                   |                |
| U/C (IDEAL)               |                 |                 | TIP SPEE  |           | 123.                           |                |
| MAX TIP SPEED             | 186.<br>1.      |                 | VOL. FLO  |           | 182.                           |                |
| STAGES DELTA H (ACT)      |                 |                 | HEAD COE  |           | 0.542                          |                |
| GAMMA                     | 1.38            |                 |   | F         | 0.172                          |                |
| PRESS RATIO (TA           | (1)             |                 |   |           |                                |                |
|                           |                 |                 |   |           |                                |                |
| ********                  |                 |                 |   | ******    |                                |                |
| # 02 TURBII               |                 |                 |   | D2 PUMP = |                                |                |
| *********                 |                 |                 | EFF I CIEN  | JCV       | 0.727                          |                |
| EFFICIENCY<br>HORSEPOHER  | 0.871<br>410.   |                 | HORSEPON  | NER       | 410.                           |                |
| SPEED (RPM                | 74295.          |                 | SPEED   |           | 74295.                         |                |
| MEAN DIA (IN              |                 |                 | S SPEED   |           | 1523.                          |                |
| EFF AREA (IN2             | 0.43            |                 | HEAD  | (FT)      | 5703.                          |                |
| U/C (IDEAL                |                 |                 | DIA.  |           | 1.93                           |                |
| MAX TIP SPEED             |                 |                 | TIP SPEE  |           | 627.                           |                |
| STAGES                    | 1.              |                 | VOL. FLO<br>HEAD COO                              |           | 181.<br>0.467                  |                |
| DELTA H LACT              | 1.38            |                 | FLOW COS  |           | 0.128                          |                |
| GAMMA PRESS RATIO (T.     |                 |                 | , con con   |           |                                |                |
| 7 NC 33 NR 110 17         |                 |                 |   |           |                                |                |
|                           |                 |                 |   |           |                                |                |
|                           |                 |                 |   |           |                                |                |
|                           | REGENERATOR     |                 |   |           |                                |                |
|                           |                 |                 |   |           |                                |                |
|                           |                 | T SIDE          |   |           |                                |                |
|                           |                 | 52.38<br>118.75 |   |           |                                |                |
|                           | 22.82 -<br>0.40 | 1.52            |   |           |                                |                |
| AREA<br>FLOH              | 5.75            | 5.69            |   |           |                                |                |
| EFFECTIVENESS             | 0.29            |                 |   |           |                                |                |
| NTU                       | 0.43            |                 |   |           |                                |                |
| CRATIO                    | 0.97            |                 |   |           |                                |                |
| CMIN                      | 20.47           |                 |   |           |                                |                |
| REGEN Q                   | 2513.80         | ı               |   |           |                                |                |
|                           |                 |                 |   |           |                                |                |

### TABLE 64. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 5.5

| ENGINE  | PERFORMANCE | PARAMETERS   |
|---------|-------------|--------------|
| ******* |             | ************ |

| CHAMBER PRESSURE          | 1665.9 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 18583. |
| DEL. VAC. ISP             | 479.0  |
| TOTAL ENGINE FLOW RATE    | 38.8   |
| THROAT AREA               | 5.547  |
| MOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 5.50   |
| CHAMBER/NOZZLE COOLANT DP | 818.   |
| CHAMBER/NOZZLE COOLANT DT | 437.   |
| ETA C*                    | 0.993  |
| CHAMBER/NOZZLE Q          | 10064. |

# ENGINE STATION CONDITIONS

|                   | * FUEL | SYSTEM CO | * SMOITIONS |          |         |
|-------------------|--------|-----------|-------------|----------|---------|
| STATION           | PRESS  | TEMP      | FLON        | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4.     | 5.98        | -107.5   | 4.37    |
| B.P. EXIT         | 101.5  | 38.5      | 5.98        | -102.9   | 4.39    |
| PUMP INLET        | 101.5  | 38.5      | 5.98        | -102.9   | 4.39    |
| IST STAGE EXIT    | 1839.4 | 63.4      | 5.98        | 6.7      | 4.41    |
| 2ND STAGE EXIT    | 3563.3 | 87.0      | 5.98        | 114.5    | 4.46    |
| PUMP EXIT         | 5278.7 | 109.7     | 5.98        | 220.4    | 4.52    |
| COLD REGEN IN     | 5223.6 | 110.1     | 5.98        | 220.4    | 4.50    |
| COLD REGEN EX     | 5168.4 | 241.7     | 5.98        | 697.7    | 2.80    |
| COOLANT INLET     | 5168.4 | 241.7     | 5.98        | 697.7    | 2.80    |
| COOLANT EXIT      | 4350.1 | 678.2     | 5.98        | 2381.6   | 1.05    |
| TBV INLET         | 4308.9 | 678.5     | 0.06        | 2381.6   | 1.04    |
| TBV EXIT          | 1925.1 | 693.0     | 0.06        | 2381.6   | 0.49    |
| LOX TRB INLET     | 4308.9 | 678.5     | 5.92        | 2381.6   | 1.04    |
| LOX TRB EXIT      | 3906.3 | 665.3     | 5.92        | 2325.7   | 0.98    |
| HC TRB INLET      | 3906.3 | 665.3     | 5.92        | 2325.7   | 0.98    |
| HZ TRB EXIT       | 2058.5 | 585.0     | 5.92        | 1999.0   | 0.61    |
| H2 TRB DIFF       | 2025.8 | 585.2     | 5.92        | 1999.0   | 0.60    |
| HC BST TRB IN     | 2003.6 | 585.3     | 5.92        | 1999.0   | 0.60    |
| H2 BST TRB EXIT   | 1983.0 | 584.1     | 5.92        | 1994.4   | 0.59    |
| HE BST TRB DIFF   | 1968.6 | 584.2     | 5.92        | 1994.4   | 0.59    |
| CC BST TRB IN     | 1946.9 | 584.3     | 5.92        | 1994.4   | 0.58    |
| OZ BST TRB EXIT   | 1937.3 | 583.6     | 5.92        | 1991.9   | 0.58    |
| 02 BST TRB DIFF   | 1935.8 | 583.6     | 5.92        | 1991.9   | 0.58    |
| H2 TANK PRESS     | 18.6   | 594.0     | 0.0081      | 1995.B   | 0.0059  |
| GOX HEAT EXCH IN  | 1925.1 | 584.8     | 5.92        | 1995.8   | 0.57    |
| GOX HEAT EXCH OUT | 1915.5 | 584.5     | 5.92        | 1994.6   | 0.57    |
| HOT REGEN IN      | 1915.5 | 584.5     | 5.92        | 1994.6   | 0.57    |
| HOT REGEN EX      | 1858.9 | 453.l     | 5.92        | 1512.5   | 0.71    |
| FSV INLET         | 1858.9 | 453.1     | 5.97        | 1512.5   | 0.71    |
| FSV EXIT          | 1811.8 | 453.2     | 5.97        | 1512.5   | 0.69    |
| CHAMBER INJ       | 1793.4 | 453.3     | 5.97        | 1512.5   | 0.69    |
| CHAMBER           | 1666.0 |           |             |          |         |
|                   |        |           |             |          |         |

|               | * OXY  | GEN SYSTEM | CONDITIONS | *        |         |
|---------------|--------|------------|------------|----------|---------|
| STATION       | PRESS  | TEMP       | FLOH       | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7      | 30.88      | 61.9     | 70.99   |
| B.P. EXIT     | 145.0  | 165.4      | 32.88      | 62.4     | 70.84   |
| PUMP INLET    | 145.0  | 155.4      | 32.88      | 62.4     | 70.84   |
| PUMP EXIT     | 3006.5 | 179.2      | 32.88      | 72.4     | 71.36   |
| 02 TANK PRESS | 16.0   | 400.0      | 0.06       | 204.7    | 0.12    |
| POSV INLET    | 2982.1 | 179.2      | 5.92       | 72.4     | 71.32   |
| POSV EXIT     | 1933.7 | 183.4      | 5.92       | 72.4     | 69.69   |
| OCV INLET     | 2982.1 | 179.2      | 26.91      | 72.4     | 71.32   |
| OCV EXIT      | 1838.6 | 183.7      | 26.91      | 72.4     | 69.53   |
| PRIMARY INJ   | 1884.8 | 183.6      | 5.92       | 72.4     | 69.61   |
| SECONDARY INJ | 1807.1 | 183.9      | 26.91      | 72.4     | 69.48   |
| CHAMBER       | 1665.9 |            |            |          |         |
|               |        |            |            |          |         |

|       | VAL     | VE DATA |       |          |
|-------|---------|---------|-------|----------|
|       | ***     | *****   |       |          |
| VALVE | DELTA P | AREA    | FLOW  | % BYPASS |
| TSV   | 2384.   | 0.003   | 0.06  | 1.00     |
| FSV   | 47.     | 1.502   | 5.47  |          |
| POSV  | 1048.   | 0.032   | 5.92  |          |
| OCV   | 1144.   | 0.141   | 26.91 |          |

|          | * FUEL * | • (     | • dixi  |
|----------|----------|---------|---------|
|          |          | PRIMARY | SEC:►D  |
| DELP MAN | 19.12    | 24.32   | 15. = = |
| DELP INJ | 108.44   | 218.93  | 141.15  |
| AREA     | 1.03     | 0.07    | 0.41    |
| FLOH     | 5.97     | 5.92    | 26.91   |
|          |          |         |         |

TABLE 64. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 5.5 (CONTINUED)

|  |               |                  | PERFORMANCE DAT      |                 |        |             |
|--|---------------|------------------|----------------------|-----------------|--------|-------------|
|  |               |                  |                      | ***<br>******** |        |             |
| * H2 BOOST   |               |                  |                      | BOOST PU        |        |             |
| ******   |               |                  |                      | *****           |        |             |
| EFFICIENCY   | 0.77          |                  |                      | NCY             |        |             |
| HORSEPOWER   | 39            |                  | HORSEPOR             | WER             | 39.    |             |
| SPEED (RPM)  | 46313         |                  | SPEED                | (RPM)           |        |             |
| MEAN DIA (IN)  |               | 4                | S SPEED              |                 | 3037.  |             |
| EFF AREA (IN2)   | 2.4           | 5                |                      | ( = 7 )         | 2723.  |             |
| U/C (IDEAL)  |               |                  | DIA.                 | (IN)            | 2.18   |             |
| MAX TIP SPEED  | 271           |                  | TIP SPE              | ΕD              | 440.   |             |
| STAGES   | 1             |                  | VOL. FLO             |                 | 611.   |             |
| DELTA H (ACT)  | 4.6           | 2                | HEAD CO              | EF              | 0.452  |             |
| GAMMA  | 1.3           | 9                | FLOH CO              | EF              | 0.201  |             |
| PRESS RATIO (T/  | TJ 1.0        | 1                |                      |                 |        |             |
|  |               |                  |                      |                 |        |             |
| ********   |               |                  |                      | ******          |        |             |
| # H2 TURBIN  |               |                  |                      | H2 PUMP         |        |             |
| ******   |               | CTACE 3          |                      | *******         |        | CTACE TIMES |
|  |               | STAGE 2          |                      |                 |        | STAGE THREE |
| FEETCTENCY   | 0 051         | #######<br>0 079 | EEEICIEANU           | 0 444           | 0 447  | ~********** |
| EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)                      | 2784          | 9776             | FLL I L'EMPA         | 0.000           | 0.66/  | U.66/       |
| SPEED (PPM)  | 123568        | 1235AR           | SPEED (PPM)          | 123569          | 123548 | 123548      |
|  |               |                  |                      |                 |        |             |
| EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELTA H GAMMA (ACT) | 0.31          | 0.40             | HEAD (FT)            | 56800           | 55940  | 54985.      |
| U/C (IDEAL)  | 0.50          | 0.40             | DIA (IN)             | 3 66            | 3 44   | 3.44        |
| MAX TIP SPEED  | 1566          | 1544             | TIP SPEED            | 1857.           | 1858   | 1858.       |
| DELTA H  | 162.          | 165.             | VOL. FLOW            | 608.            | 602.   | 593.        |
| GAMMA (ACT)  | 1.39          | 1.39             | HEAD COFF            | 0.530           | 0.522  | 0.513       |
| PRESS RATIO(T/T  | 1.34          | 1.37             | FLOW COEF            | 0.100           | 0.100  | 0.100       |
|  |               |                  |                      |                 |        |             |
| ********   | ******        |                  |                      | *****           | ***    |             |
| * 02 BOOST   | TURBINE .     |                  | • 02                 | BOOST PU        | 4P #   |             |
| *******  | *******       |                  |                      | *****           |        |             |
| EFFICIENCY   | 0.866         | •                | EFFICIEN             |                 | 0.755  |             |
| HORSEPOWER   | 21.           |                  | HOR SEP OF           | ÆR              | 21.    |             |
| SPEED (RPM)  | 12219.        |                  | SPEED                | (RPM)           | 12219. |             |
| MEAN DIA (IN)  | 3.65          | 1                | S SPEED              |                 | 2705.  |             |
| EFF AREA (IN2)   |               | 1                | HEAD<br>DIA.         | (FT)            | 262.   |             |
| U/C [IDEAL]  |               |                  |                      |                 | 2.44   |             |
| MAX TIP SPEED  |               |                  | TIP SPEE             |                 | 130.   |             |
| STAGES   | 1.            |                  | VOL. FLO             |                 | 208.   |             |
| DELTA H (ACT)  |               |                  | HEAD COE             |                 | 0.497  |             |
| GAMMA PRESS RATIO (1/)                                       | 1.39          |                  | FLOH COE             | .F              | 0.186  |             |
| PRESS MALID (17  | 1.00          |                  |                      |                 |        |             |
| ********   |               |                  |                      | ******          |        |             |
| # 02 TURBINE   |               |                  |                      | 2 PUMP *        |        |             |
| *********  |               |                  |                      | *******         |        |             |
|  |               |                  |                      |                 | 0.737  |             |
|  | 0.865<br>468. |                  | EFFICIEN<br>HORSEPOH | ιER             | 468.   |             |
| SPEED (RPM)  | 76597.        |                  | SPEED                |                 | 76597. |             |
| MEAN DIA (IN)  | 2.86          |                  | S SPEED              |                 | 1663.  |             |
| EFF AREA (IN2)   | 0.43          |                  | HEAD                 | (FT)            | 5773.  |             |
| U/C (IDEAL)  |               |                  | DIA.                 | (IN)            | 1.43   |             |
| MAX TIP SPEED  | 957.          |                  | TIP SPEE             | D               | 647.   |             |
| STAGES   | 1.            |                  | VOL. FLO             |                 | 207.   |             |
| DELTA H (ACT)  |               |                  | HEAD COE             |                 | 0.444  |             |
| GAMMA  | 1.39          |                  | FLOW COE             | F               | 0.141  |             |
| PRESS RATIO (T/1   | 1.10          |                  |                      |                 |        |             |
|  |               |                  |                      |                 |        |             |
|  |               |                  |                      |                 |        |             |
| _  |               |                  |                      |                 |        |             |
|  | REGENERATO    |                  |                      |                 |        |             |
|  |               |                  |                      |                 |        |             |
|  | SIDE H        |                  |                      |                 |        |             |
|  | 5.26          | 56.56            |                      |                 |        |             |
|  |               | -131.40          |                      |                 |        |             |
|  | 0.40          | 1.52             |                      |                 |        |             |
|  | 5.98          | 5.92             |                      |                 |        |             |
| EFFECTIVENESS  | 0.2           |                  |                      |                 |        |             |
| NTU  | 0.4           |                  |                      |                 |        |             |
| CRATIO   | 1.0           |                  |                      |                 |        |             |
| CMIN<br>DECEN O  | 21.6          |                  |                      |                 |        |             |
| REGEN Q  | 2852.6        | ′                |                      |                 |        |             |
|  |               |                  |                      |                 |        |             |

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#### TABLE 65. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 6.0

STATION

B.P. INLET B.P. EXIT

PUMP INLET

PUMP EXIT

TBV EXIT

FSV INLET

FSV EXIT CHAMBER INJ

CHAMBER

STATION

B.P. INLET B.P. EXIT

PUMP INLET

PUMP EXIT

POSV INLET POSV EXIT

OCV INLET

CHAMBER

#### ENGINE PERFORMANCE PARAMETERS .......... CHAMBER PRESSURE VAC ENGINE THRUST 20000. DEL. VAC. ISP TOTAL ENGINE FLOW RATE 489.1 41.7 HOZZLE AREA RATIO THROAT AREA 1000.0 ENGINE MIXTURE RATIO 6.00 CHAMBER/NOZZLE COOLANT DP CHAMBER/NOZZLE COOLANT DT 585. ETA C\* 0.993 CHAMBER/NOZZLE Q 11390. ENGINE STATION CONDITIONS \* FUEL SYSTEM CONDITIONS \* TEMP FLOW PRESS FMTHM PY DENSITY 37.4 -107.5 18.6 5.96 4.37 5.96 -163.0 4.39 100.3 38.5 100.3 38.5 5.96 -103.0 4.39 1ST STAGE EXIT 63.9 88.1 1882.3 5.96 9.2 4.41 115.6 5.96 4.46 3651.4 5.96 228.1 4.53 COLD REGEN IN 5359.5 111.7 5.96 228.1 4.51 794.2 5.96 2.67 COLD REGEN EX 5305.2 263.0 COOLANT INLET 5305.2 263.0 790.2 COOLANT EXIT 4431.2 767.8 5.96 2781.8 0.96 2781.8 0.95 TBV INLET 4386.0 768.1 0.36 2030.5 LOX TRB INLET 4386.0 768.1 5.60 2761.8 0.95 753.6 2640.8 0.88 3984.6 LOX TRB EXIT 5.60 753.6 5.60 2640.8 0.88 HC TRB INCET H2 TRB EXIT 2159.4 665.3 5.60 2288.6 0.57 665.5 2288.6 H2 TRB DIFF 5.64 0.56 2127.6 HC BST TRB IN 2106.2 665.6 HC BST TRB EXIT 2086.3 664.4 5.60 2283.8 0.55 2283.8 0.55 HE BST TRB DIFF 2072.4 664.5 5.68 02 BST TRB IN 2051.5 664.6 5.60 02 BST TRB EXIT 2042.2 663.9 5.60 2281.3 0.54 2281.3 0.54 O2 BST TRB DIFF 2040.7 663.9 5.40 HZ TANK PRESS 682.3 0.0070 0.0051 18.6 GOX HEAT EXCH IN 2030.5 671.1 5.60 2586.4 0.53 GOX HEAT EXCH OUT 2021.2 670.7 5.60 2304.9 0.53 670.7 2304.9 HOT REGEN IN 2021.2 5.60 HOT REGEN EX 505.4 5.60 1707.1 0.67 1966.2 505.4 5.95 1767.1 0.67 5.95 1916.8 505.6 1707.1 505.7 1707.1 0.65 1764.0 \* OXYGEN SYSTEM CONDITIONS \* PRESS TEMP FLON ENTHALPY DENSITY 162.7 35.77 61.9 70.99 16.0 134.0 165.3 134.0 165.3 35.77 62.3 70.84 2854.8 178.4 35.77 71.9 71.34 02 TANK PRESS 16.0 400.0 0.06 178.5 5.32 71.9 71.30 1979.3 181.8 5.32 71.9 69.98 178.5 30.39 71.30 71.9 2825.9 181.7 30.39 71.9 69.99 LNI YARMIRA 1940.0 181.9 5.32 71.9 69.92 SECONDARY INJ 1943.0 181.9 30.39 69.92 1764.0 VALVE DATA

|       | *       |           |       |          |
|-------|---------|-----------|-------|----------|
|       | 4 # #   | ****      |       |          |
| VALVE | DELTA P | AREA      | FLON  | & BYPASS |
| TBV   | 2356.   | 0.016     | 0.36  | 5.97     |
| FSV   | 49.     | 1.502     | 5.95  |          |
| POSV  | 847.    | 0.032     | 5.32  |          |
| DCV   | 843.    | 0.185     | 30.39 |          |
|       |         |           |       |          |
|       | INJE    | CTOR DATA |       |          |

|          | * FUEL * | . (     | oxid • |
|----------|----------|---------|--------|
|          |          | PRIMARY | SECOND |
| DELP MAN | 20.01    | 19.55   | 19.88  |
| DELP INJ | 1:3.49   | 175.97  | 178.93 |
| AREA     | 1.03     | 0.07    | 0.41   |
| FLOH     | 5.95     | 5.32    | 30.34  |
|          |          |         |        |

TABLE 65. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 6.0 (CONTINUED)

| PAGE ANNO REPORT OF THE PAGE AND A PAGE AND |  |                            |
|---|--|----------------------------|
| * TURBOMACHINERY P  |  |                            |
|   |  |                            |
| # H2 BOOST TURBINE #  | # H2 BOOST PL                                      |                            |
| ***********   | ********   | ***                        |
| EFFICIENCY 0.770<br>HORSEPOHER 38.  | EFFICIENCY   |                            |
| HORSEPOHER 38.<br>SPEED (RPM) 46052.  | HORSEPOWER   | 38.                        |
| SPEED (RPM) 46052.  | SPEED (RPM)<br>S SPEED                             | 46052.<br>3049.            |
| FFF ARFA (IN2) 2.45   | HEAD (FT)  | 2683.                      |
| U/C (IDEAL) 0.485   | HEAD (FT)<br>DIA. (IN)                             | 2.18                       |
| MEAN DIA (IN) 1.34<br>EFF AREA (IN2) 2.45<br>U/C (IDEAL) 0.485<br>MAX TIP SPEED 269.  | TIP SPEED  | 438.                       |
| 5!AU-E.5   .  | VOL. FLOH  | 609.                       |
| DELTA H (ACT) 4.79 GAMMA 1.36   | MEAD COEF<br>FLOW COEF                             | 0.450<br>0.202             |
| PRESS RATIO (T/T) 1.01  | FEUR COEF  | 0.202                      |
|   |  |                            |
| *****   | *******  |                            |
| # H2 TURBINE #  | # H2 PUMP  |                            |
| BERNARRANANA<br>CTACE ) CTACE 2   | STACE ONE  | STAGE THO STAGE THREE      |
| 3/AGE 1 3/AGE 2<br>BRANKAN MAKRANA  | STAGE ONE  |                            |
| EFFICIENCY 0.839 0.828  | EFFICIENCY 0.667                                   | 0.668 0.668                |
| HORSEPOMER 2792. 2792.  | HORSEPOWER 946.                                    | 931. 915.                  |
| SPEED (RPM) 124577. 124577.   | SPEED (RPM) 124577.                                | 124577. 124577.            |
| ######################################  | S SPEED 818.                                       | 823. 827.                  |
| EFF AREA (IN2) 0.31 0.40  | HEAD IFF) 58219.                                   | 5/358. 56415.<br>7 44 7 44 |
| HAX TIP SPEED 1557. 1557.   | TIP SPEED 1872.                                    | 1873. 1873.                |
| DELTA H 176. 176.   | VOL. FLOH 606.                                     | 599. 590.                  |
| GAMMA (ACT) 1.36 1.36   | HEAD COEF 0.534                                    | 0.526 0.517                |
| PRESS RATIO(T/T 1.34 1.37   | FLOH COEF 0.098                                    | 0.099 0.099                |
| ******  | *******  |                            |
| # 02 BOOST TURBINE #  | ■ 02 BOOST PU                                      |                            |
| **********  | *******  |                            |
| EFFICIENCY 0.861 HGRSEPOHER 20. SPEED (RPH) 12293. MCAN DIA (IN) 3.69   | EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)            | 0.764                      |
| HGRSEPOHER 20.  | HORSEPOWER   | 20.                        |
| SPEED (RPM) 12293. MEAN DIA (IN) 3.69   | SPEED (RPM)<br>S SPEED                             | 12293.<br>3036.            |
| 555 1051 (111) 3.07   | HEAD (FT)  | 240.                       |
| U/C (IDEAL) 0.514 MAX TIP SPEED 198.  | HEAD (FT)<br>DIA. (IN)<br>TIP SPEED                | 2.44                       |
| MAX TIP SPEED 198.  | TIP SPEED  |                            |
| STAGES 1.   | VOL. FLOM<br>HEAD COEF                             | 227.<br>0.449              |
| DELTA H (ACT) 2.58 GAMMA 1.36   | HEAD COEF<br>FLOW COEF                             | 0.449                      |
| PRESS RATIO (T/T) 1.00  | FEOR COEF  | 0.201                      |
|   |  |                            |
|   | *****  |                            |
| * 02 TURBINE *  | # 02 PUMP #  |                            |
| EEEICIEUCV 0 950  | ##########<br>EFFICIENCY                           |                            |
| HORSEPOMER 483.   | EFFICIENCY<br>HORSEPOWER<br>SPEED (RPM)<br>S SPEED | 483.                       |
| SPEED (RPM) 76647.  | SPEED (RPM)  | 76647.                     |
| EFFICIENCY 0.850 HORSEPOMER 483. SPEED (RPM) 76647. MEAN DIA (IN) 2.86 EFF AREA (IN2) 0.43  |  |                            |
| EFF AREA (IN2) 0.43   | HEAD (FT)<br>DIA. (IN)                             | 5490.                      |
| U/C (IDEAL) U.SUS   | DIA. (IN)<br>TIP SPEED                             | 1.93<br>647.               |
| MAX TIP SPEED 958.<br>STAGES 1.   | VOL. FLOH  | 225.                       |
| DELTA H (ACT) 60.92   | HEAD COEF<br>FLOW COEF                             | 0.422                      |
| GAMMA 1.36  | FLOW COEF  | 0.154                      |
| PRESS RATIO (T/T) 1.10  |  |                            |
|   |  |                            |
|   |  |                            |
| REGENERATOR DATA  |  |                            |
| ***********   |  |                            |
| COLD SIDE HOT SIDE<br>DELP 54.26 55.05  |  |                            |
| DELP 54.26 55.05<br>DELT 151.37 -165.29   |  |                            |
| AREA 0.40 1.52  |  |                            |
| FLOH 5.96 5.60  |  |                            |
| EFFECTIVENESS 0.30  |  |                            |
| NTU 0.43  |  |                            |
| CRATIO 0.92   |  |                            |
| CMIN 20.26<br>REGEN Q 3349.23   |  |                            |
|   |  |                            |

### TABLE 66. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 6.5

## ENGINE PERFORMANCE PARAMETERS

| CHAMBER PRESSURE          | 1764.0 |
|---------------------------|--------|
| VAC ENGINE THRUST         | 20336. |
| DEL. VAC. ISP             | 480.3  |
| TOTAL ENGINE FLOW RATE    | 42.3   |
| THROAT AREA               | 5.547  |
| NOZZLE AREA RATIO         | 1000.0 |
| ENGINE MIXTURE RATIO      | 6.50   |
| CHAMBER/NOZZLE COOLANT DP | 884.   |
| CHAMBER/NOZZLE COOLANT DT | 578.   |
| ETA C*                    | 0.993  |
| CHAMBER/NOZZLE Q          | 12145. |

### ENGINE STATION CONDITIONS

|                   | # FUEL | SYSTEM CO | ONDITIONS . |          |         |
|-------------------|--------|-----------|-------------|----------|---------|
| STATION           | PRESS  | TEMP      | FLOH        | ENTHALPY | DENSITY |
| B.P. INLET        | 18.6   | 37.4      | 5.65        | -107.5   | 4.37    |
| B.P. EXIT         | 95.5   | 38.4      | 5.65        | -103.5   | 4.39    |
| PUMP INLET        | 95.5   | 38.4      | 5.65        | -103.3   | 4.39    |
| 1ST STAGE EXIT    | 1804.2 | 62.9      | 5.65        | 4.5      | 4.41    |
| 2ND STAGE EXIT    | 3498.9 | 86.1      | 5.65        | 110.5    | 4.46    |
| PUMP EXIT         | 5184.6 | 108.4     | 5.65        | 214.5    | 4.52    |
| COLD REGEN IN     | 5135.3 | 108.8     | 5.65        | 214.5    | 4.50    |
| COLD REGEN EX     | 5085.7 | 292.4     | 5.65        | 911.6    | 2.40    |
| COOLANT INLET     | 5085.7 | 292.4     | 5.65        | 911.6    | 2.40    |
| COOLANT EXIT      | 4201.5 | 870.3     | 5.45        | 3060.9   | 0.81    |
| TBV INLET         | 4153.7 | 870.6     | 0.71        | 3060.9   | 0.80    |
| TBV EXIT          | 2021.1 | 884.8     | 0.71        | 3060.9   | 0.41    |
| LOX TRB INLET     | 4153.7 | 870.6     | 4.94        | 3060.9   | 0.80    |
| LOX TRB EXIT      | 3780.9 | 854.6     | 4.94        | 2995.6   | 0.75    |
| H2 TRB INLET      | 3780.9 | 854.6     | 4.94        | 2995.6   | 0.75    |
| H2 TRB EXIT       | 2136.8 | 762.9     | 4.94        | 2632.4   | 0.49    |
| H2 TRB DIFF       | 2108.2 | 763.0     | 4.94        | 2632.4   | 0.49    |
| H2 BST TRB IN     | 2089.0 | 763.2     | 4.94        | 2632.4   | 0.48    |
| H2 BST TRB EXIT   | 2071.1 | 761.9     | 4.94        | 2627.6   | 0.48    |
| H2 BST TRB DIFF   | 2058.6 | 762.0     |             | 2627.6   | 0.48    |
| 02 BST TRB IN     | 2039.9 | 762.1     | 4.94        | 2627.6   | 0.47    |
| OZ BST TRB EXIT   | 2031.5 | 761.4     | 4.94        | 2624.9   | 0.47    |
| 02 BST TRB DIFF   | 2030.2 | 761.4     | 4.94        | 2624.9   | 0.47    |
|                   | 18.6   | 789.1     |             | 2679.4   | 0.0045  |
| GOX HEAT EXCH IN  | 2021.1 | 776.9     |             | 2679.4   | 0.46    |
| GOX HEAT EXCH OUT |        | 776.4     |             | 2677.7   | 0.46    |
| HOT REGEN IN      | 2012.7 | 776.4     | 4.94        | 2677.7   | 0.46    |
| HOT REGEN EX      | 1963.1 | 553.1     | 4.94        | 1881.1   | 0.62    |
| FSV INLET         | 1963.1 | 553.1     | 5.64        | 1881.1   | 0.62    |
| FSV EXIT          | 1914.4 | 553.4     | 5.64        | 1881.1   | 0.60    |
| CHAMBER INJ       | 1895.5 | 553.4     | 5.64        | 1881.1   | 0.60    |
| CHAMBER           | 1764.1 |           |             |          |         |

|               | * OXY  | EN SYSTEM | CONDITIONS | S *      |         |
|---------------|--------|-----------|------------|----------|---------|
| STATION       | PRESS  | TEMP      | FLOW       | ENTHALPY | DENSITY |
| B.P. INLET    | 16.0   | 162.7     | 36.75      | 61.9     | 70.99   |
| B.P. EXIT     | 117.1  | 165.2     | 36.75      | 62.3     | 70.83   |
| PUMP INLET    | 117.1  | 165.2     | 36.75      | 62.3     | 70.83   |
| PUMP EXIT     | 2607.6 | 177.3     | 36.75      | 71.1     | 71.28   |
| 02 TANK PRESS | 16.0   | 400.0     | 0.06       | 204.7    | 0.12    |
| POSV INLET    | 2577.0 | 177.4     | 4.65       | 71.1     | 71.23   |
| POSV EXIT     | 1928.2 | 179.9     | 4.65       | 71.1     | 70.22   |
| OCV INLET     | 2577.0 | 177.4     | 32.04      | 71.1     | 71.23   |
| OCV EXIT      | 2006.1 | 179.6     | 32.04      | 71.1     | 70.34   |
| PRIMARY INJ   | 1898.3 | 180.0     | 4.65       | 71.1     | 70.17   |
| SECONDARY INJ | 1961.9 | 179.8     | 32.04      | 71.1     | 70.27   |
| CHAMBER       | 1764.0 |           |            |          |         |

|       |         | VE DATA |       |          |
|-------|---------|---------|-------|----------|
| VALVE | DELTA P | AREA    | FLOW  | s poper  |
| TBV   | 2133.   | 0.036   | 0.71  | % BYPASS |
| FSV   | 49.     | 1.502   | 5.64  | 12.50    |
| POSV  | 649.    | 0.032   |       |          |
| OCV   |         |         | 4.65  |          |
| UC V  | 571.    | 0.238   | 32.04 |          |

|          | * FUEL * |         | OXID .  |
|----------|----------|---------|---------|
|          |          | PRIMARY | SECOND. |
| DELP MAN | 19.65    | 14.92   | 21.44   |
| DELP INJ | 111.83   | 134.23  | 197.88  |
| AREA     | 1.03     | 0.07    | 0.41    |
| FLOW     | 5.64     | 4.65    | 32.04   |

# TABLE 66. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 6.5 (CONTINUED)

| *********                                       |  |                         |
|---|--|-------------------------|
| * TURBOMACHINERY PE                             |  |                         |
| *******************                             | ****************                       |                         |
| * H2 BOOST TURBINE *                            | # H2 BOOST PUMP #                      |                         |
|   | *********                              |                         |
| EFFICIENCY 0.750                                | EFFICIENCY 0.3                         |                         |
| HORSEPOHER 34.                                  |  | 34.                     |
| SPEED (RPH) 44288.                              | SPEED (RPM) 4428<br>S SPEED 298        |                         |
| MEAN DIA (IN) 1.34<br>EFF AREA (IN2) 2.45       | HEAD (FT) 252                          |                         |
| U/C (IDEAL) 0.485                               | DIA. (IN) 2                            |                         |
| MAX TIP SPEED 259.                              | TIP SPEED 43                           | 21.                     |
| STAGES 1.                                       | VOL. FLOH 5                            |                         |
| DELTA H (ACT) 4.85                              | HEAD COEF 0.4                          |                         |
| GAMMA 1.38 PRESS RATIO (T/T) 1.01               | FLOW COEF 0.                           | 177                     |
| FRESS RATIO (171)                               |  |                         |
| ***   | ******                                 |                         |
| # H2 TURBINE #                                  | # H2 PUMP #                            |                         |
| ******  | STACE ONE STACE                        | E THO STAGE THREE       |
| STAGE 1 STAGE 2                                 | *****                                  | *****                   |
| EFFICIENCY 0.813 0.810                          | EFFICIENCY 8.666 0                     | .667 0.668              |
| HORSEPOHER 2541. 2541.                          | EFFICIENCY 8.666 0<br>HORSEPONER 862.  | 847. 832.               |
| SPEED (RPM) 121121. 121121.                     | SPEED (RPM) 121121. 121                | 121. 121121.            |
| MEAN DIA (IN) 2 R6 2.R6                         | S SPEED 799. 1<br>HEAD (FT) 55857. 550 | 804. 809.               |
| EFF AREA (IN2) 0.31 0.40                        | HEAD (FT) 55857. 550                   |                         |
| U/C (IDEAL) 0.448 0.455                         | DIA. (IN) 3.44<br>TIP SPEED 1821. 18   | 3.44 3.44<br>821. 1821. |
| MAX TIP SPEED 1513. 1513.<br>DELTA H 185. 179.  | VOL. FLON 575.                         | 569. 561.               |
| DELTA H 185. 179.                               | HEAD CORF 0.542 0                      | .534 0.525              |
| GAMMA (ACT) 1.38 1.38 PRESS RATIO(T/T 1.34 1.37 | FLOH COEF 0.096 0                      | .096 0.097              |
|   |  |                         |
| <b>经国际股票公司</b>                                  | ###################################### |                         |
| H O2 BOOST TURBINE H                            | # UZ BOOS1 FOW "                       |                         |
| EFFICIENCY 0.842                                |  | 753                     |
| HORGEPOHER 18.                                  |  | 18.                     |
| SPEED (RPM) 11907.                              | SPEED (RPH) 119                        |                         |
| MEAN DIA (IN) 3.69                              | 2 SPEED 33                             |                         |
| EFF AREA (IN2) 3.60                             |  | 06.                     |
| U/C (1DEAL) 0.514                               |  | .44<br>27.              |
| MAX TIP SPEED 192.<br>STAGES 1.                 |  | 33.                     |
| DELTA H (ACT) 2.61                              |  | 410                     |
| GAMMA 1.38                                      |  | 213                     |
| PRESS RATIO (T/T) 1.00                          |  |                         |
|   | ********                               |                         |
| * O2 TURBINE *                                  | # 02 PUMP #                            |                         |
| * UZ IURDINE *                                  | ********                               |                         |
| EFFICIENCY 0.821                                | EFFICIENCY 0.                          | 735                     |
| HORSEPOHER 457.                                 |  | 57.                     |
| SPEED (RPM) 74858.                              | SPEED (RPH) 748                        |                         |
| MEAN DIA (IN) 2.86                              | S SPEED 19<br>HEAD (FT) 50             | 30.                     |
| EFF AREA (1N2) 0.43<br>U/C (IDEAL) 0.468        |  | .93                     |
| MAX TIP SPEED 935.                              |  | 32.                     |
| STAGES 1.                                       | VOL. FLOH 2                            | 31.                     |
| DELTA H (ACT) 65.35                             |  | 405                     |
| GAMMA 1.38                                      | FLOM COEF 0.                           | 162                     |
| PRESS RATIO (T/T) 1.10                          |  |                         |
|   |  |                         |
|   |  |                         |
| REGENERATOR DATA                                |  |                         |
| ***********                                     |  |                         |
| COUD SIDE HOT SIDE  DELP 49.62 49.67            |  |                         |
| DCC   |  |                         |
| DELT 183.57 -223.29 AREA 0.40 1.52 -            |  |                         |
| FLOH 5.65 4.94                                  |  |                         |
| EFFECTIVENESS 0.33                              |  |                         |
| NTU 0.50  |  |                         |
| CRATIO 0.82                                     |  |                         |
| CMIN 17.64 REGEN 0 3938.60                      |  |                         |
| REGEN Q 3938.60                                 |  |                         |
|   |  |                         |

### TABLE 67. - FULL-EXPANDER CYCLE WITH REGENERATION - O/F = 7.0

DELP MAN

DELP INJ AREA

|   | ENGINE F                   |                   | E PARAMETEI    |                           |                |
|---|----------------------------|-------------------|----------------|---------------------------|----------------|
| •   |                            |                   |                |                           |                |
|   | MBER PRESSU<br>ENGINE THR  |                   |                | 1763.9<br>20672.          |                |
|   | . VAC. ISP                 |                   |                | 477.5                     |                |
|   | AL ENGINE F                | LOW RATE          |                | 43.3<br>5.547             |                |
|   | DAT AREA<br>ZLE AREA RA    | 110               |                | 1000.0                    |                |
| ENG   | INE MIXTURE                | RATIO             |                | 7.00                      |                |
|   | MBER/NOZZLE<br>MBER/NOZZLE |                   |                | 890.<br>650.              |                |
| ETA   |                            | COOLANI           | U              | 0.988                     |                |
| CHA   | MBER/NOZZLE                | 0                 |                | 12914.                    |                |
|   |                            | *******           | CONDITIONS     |                           |                |
| STATION                                       | * FUEL<br>PRESS            | SYSTEM CO         | NDITIONS .     | ENTHALPY                  | DENSITY        |
| B.P. INLET                                    | 18.6                       | 37.4              | 5.42           | -107.5                    | 4.37           |
| B.P. EXIT                                     | 91.8                       | 38.4              | 5.42           | -103.5                    | 4.39           |
| PUMP INLET                                    | 91.8<br>1748.8             | 38.4              | 5.42<br>5.42   | -103.5<br>1.2             | 4.39<br>4.41   |
| 1ST STAGE EXIT<br>2ND STAGE EXIT              | 3390.2                     | 62.2<br>84.8      | 5.42           | 104.1                     | 4.45           |
| PUMP EXIT                                     | 5020.7                     | 106.5             | 5.42           | 205.1                     | 4.51           |
| COLD REGEN IN                                 | 4975.3                     | 106.9             | 5.42           | 205.1                     | 4.49           |
| COLD REGEN EX<br>COOLANT INLET                | 4929.1<br>4929.1           | 316.9<br>316.9    | 5.42<br>5.42   | 1013.2<br>1013.2          | 2.20<br>2.20   |
| COOLANT EXIT                                  | 4038.9                     | 967.2             | 5.42           | 3397.2                    | 0.71           |
| TBV INLET                                     | 3988.8                     | 967.5             | 0.95           | 3397.2                    | 0.70           |
| TBV EXIT                                      | 2015.4                     | 981.1             | 0.95           | 3397.2<br>3397.2          | 0.37<br>0.70   |
| LOX TRB INLET<br>LOX TRB EXIT                 | 1988.8<br>3637.6           | 967.5<br>950.2    | 4.47<br>4.47   | 3328.2                    | 0.66           |
| H2 TRB INLET                                  | 3637.6                     | 950.2             | 4.47           | 3328.2                    | 0.66           |
| H2 TRB EXIT                                   | 2121.5                     | 853.8             | 4.47           | 2954.2                    | 0.44           |
| H2 TRB DIFF                                   | 2095.2                     | 853.9<br>854.0    | 4.47<br>4.47   | 2954.2<br>2954.2          | 0.44           |
| H2 BST TRB IN H2 BST TRB EXIT H2 BST TRB DIFF | 2061.2                     | 852.8             | 4.47           | 2949.3                    | 0.43           |
| H2 BST TRB DIFF                               |                            | 852.8             | 4.47           | 2949.3                    | 0.43           |
| OZ BST TRB IN                                 | 2032.7                     | 852.9<br>852.3    | 4.47<br>4.47   | 2949.3<br>2946.6          | 0.42<br>0.42   |
| O2 BST TRB EXIT<br>O2 BST TRB DIFF            | 2023.8                     | 852.3             | 4.47           | 2946.6                    | 0.42           |
| H2 TANK PRESS                                 | 18.6                       | 887.8             | 0.0049         | 3025.5                    | 0.0039         |
| GOX HEAT EXCH IN                              | 2015.4                     | 874.7             | 4.47           | 3025.5                    | 0.41           |
| GOX HEAT EXCH OUT<br>HOT REGEN IN             | 7 2007.8<br>2007.8         | 874.2<br>874.2    | 4.47<br>4.47   | 3023.6<br>302 <b>3</b> .6 | 0.41           |
| HOT REGEN EX                                  | 1962.1                     | 597.9             | 4.47           | 2043.9                    | 0.57           |
| FSV INLET                                     | 1962.1                     | 597.9             | 5.41           | 2043.9                    | 0.57           |
| FSV EXIT                                      | 1913.6                     | 598.2             | 5.41           | 2043.9                    | 0.56<br>0.56   |
| CHAMBER INJ<br>CHAMBER                        | 1894.9<br>1764.2           | 598.3             | 5.41           | 2043.9                    | 0.56           |
|   |                            | EN SYSTEM<br>TEMP | CONDITIONS     | S #<br>ENTHALPY           | DENSITY        |
| STATION<br>B.P. INLET                         | PRESS<br>16.0              | 162.7             | 37.95          | 61.9                      | 70.99          |
| B.P. EXIT                                     | 101.6                      | 165.2             | 37.95          | 62.2                      | 70.82          |
| PUMP INLET                                    | 101.6                      | 165.2             | 37.95          | 62.2                      | 70.82          |
| PUMP EXIT                                     | 2379.8<br>16.0             | 176.4<br>400.0    | 37.95<br>0.06  | 70.4<br>204.7             | 71.20<br>0.12  |
| OZ TANK PRESS<br>POSV INLET                   | 2347.2                     | 176.5             | 3.94           | 70.4                      | 71.15          |
| POSV EXIT                                     | 1880.9                     | 178.3             | 3.94           | 70.4                      | 70.42          |
| OCV INLET                                     | 2347.2                     | 176.5             | 33.94<br>33.94 | 70.4<br>70.4              | 71.15<br>70.66 |
| OCV EXIT<br>PRIMARY INJ                       | 2034.5<br>1859.4           | 177.7<br>178.4    | 3.94           | 70.4                      | 70.39          |
| SECONDARY INJ                                 | 1985.1                     | 177.9             |                | 70.4                      | 70.58          |
| CHAMBER                                       | 1763.4                     |                   |                |                           |                |
|   |                            | VE DATA           |                |                           |                |
| VALVE   | DELTA P                    |                   | FLOM           | 1 BYPASS                  |                |
| TBV   | 1973.<br>48.               | 0.053             | 0.95<br>5.41   | 17.51                     |                |
| FSV<br>POSV                                   | 48.<br>466.                | 1.502<br>0.032    | 5.41<br>3.94   |                           |                |
| 0CA   | 313.                       | 0.340             |                |                           |                |
|   | 3L <b>HI</b>               | CTOR DATA         |                |                           |                |
| _   |                            | ********          |                |                           |                |
| ■ FUEL  |                            | IXO *<br>Y&a≌'    |                |                           |                |

PRIMARY 10.98 96.38

5.94

19.45

111.54

1.05

SECOND 24.56 221.10

0.41 31.94

TABLE 67. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 7.0 (CONTINUED)

| ######################################   |                           |                            |
|--|---------------------------|----------------------------|
| TURBOMACHINERY PI  |                           |                            |
|  | ****                      | ***                        |
| # H2 BOOST TURBINE #   | # H2 BOOST PU             |                            |
| *****  | ********                  |                            |
| EFFICIENCY 0.734   | EFFICIENCY                | 0.765                      |
| HORSEPOHER 31.   | HORSEPOHER                | 31.                        |
| SPEED (RPM) 42920.   |                           | 42920.                     |
| MEAN DIA (IN) 1.34<br>EFF AREA (IN2) 2.45  | S SPEED                   | 2940.                      |
|  | HEAD (FT)<br>DIA. (IN)    | 2406.                      |
| U/C (1DEAL) 0.485  | DIA. (IN)<br>TIP SPEED    | 2.18<br>408.               |
| MAX TIP SPEED 251.<br>STAGES 1.  | VOL. FLOH                 | 554.                       |
| DELTA H (ACT) 4.90   | MEAD COEE                 | 0 465                      |
| GAMMA 1.40   | FLOW COEF                 | 0.197                      |
| PRESS RATIO (T/T) 1.01   |                           |                            |
|  |                           |                            |
| ********   | <b>被放弃的</b>               |                            |
| # H2 TURBINE #   | # H2 PUMP                 |                            |
| ######################################   | RHARRAGEA<br>STACE ONE    | STAGE THO STAGE THREE      |
| STAGE 1 STAGE 2  |                           |                            |
| FEETCIENCY 0.792 0.795   | EFFICIENCY 0.665          | 0.666 0.667                |
| EFFICIENCY 0.792 0.795<br>HORSEPOMER 2345. 2365.<br>SPEED (RPM) 118602. 118602.<br>MEAN DIA (IN) 2.86 2.86<br>EFF AREA (1N2) 0.31 0.40 | HORSEPOWER 802.           | 789. 774.                  |
| SPEED (RPM) 118602. 118602.  | SPEED (RPM) 118602.       | 118602. 118602.            |
| MEAN DIA (IN) 2.86 2.86  | S SPEED 784.              | 790. 795.                  |
| EFF AREA (1H2) 0.31 0.40   | HEAD (FT) 54197.          | 53348. 52410.              |
| U/C (IDEAL) 0.425 0.438  | DIA. (IN) 3.44            | 3.44 3.44                  |
| MAX TIP SPEED 1482. 1482.  | TIP SPEED 1783.           | 1783. 1783.<br>547. 539.   |
| U/C (IDEAL) 0.425 0.438 MAX TIP SPEED 1482. 1482. DELTA H 192. 182. GAMMA (ACT) 1.40 1.40 PRESS RATIO(T/T 1.34 1.37                    | HEAD COSE 0.549           | 0.540 0.530                |
| PRESS PATINITYT 1.34 1.37  | FLOW COEF 0.094           | 0.540 0.530<br>0.095 0.095 |
| TRESS RATIOTITY  |                           |                            |
| ********   | ******                    |                            |
| # 02 BOOST TURBINE #   | ■ 02 BOOST PU             |                            |
| ***********  | ********                  |                            |
| EFFICIENCY 0.826   | EFFICIENCY<br>HORSEPOHER  | 0.721<br>17.               |
| HORSEPOHER 17.   | SPEED (RPM)               | 11576                      |
| SPEED (RPM) 11574.<br>MEAN DIA (IN) 3.69   | S SPEED (RFR)             | 3743.                      |
| FEE AREA (IN2) 3.60  |                           | 174.                       |
| EFF AREA (IN2) 3.60<br>U/C (IDEAL) 0.514   | HEAD (FT)<br>DIA. (IN)    | 2.44                       |
| MAX TIP SPEED 186.   | TIP SPEED                 | 123.                       |
| STAGES 1.  | VOL. FLOW                 | 241.                       |
| DELTA H (ACT) 2.64   | HEAD COEF<br>FLOW COEF    | 0.368                      |
| GAMMA 1.40 PRESS RATIO (T/T) 1.00  | FLOM COEF                 | 0.226                      |
| PRESS RATIO (171) 1.00   |                           |                            |
|  | ****                      |                            |
| # 02 TURBINE #   | # O2 PUMP #               |                            |
| *******  | ****                      |                            |
| EFFICIENCY 0.796<br>HORSEPOHER 436.  | EFFICIENCY                | 0.729                      |
| HORSEPOHER 436.  | HORSEPOHER<br>SPEED (RPM) |                            |
| SPEED (RPM) 73352.<br>MEAN DIA (IN) 2.86   | S SPEED (RPM)             | 73352.<br>2029.            |
| MEAN DIA (IN) 2.86<br>EFF AREA (IN2) 0.43  |                           |                            |
| U/C (IDEAL) 0.440  | HEAD (FT)<br>DIA. (IN)    | 1.93                       |
| MAX TIP SPEED 917.   | TIP SPEED                 | 619.                       |
| STAGES 1.  | VOL. FLOH                 | 239.                       |
| DELTA H (ACT) 68.96  | HEAD COEF                 | 0.387                      |
| GAMMA 1.40   | FLOW COEF                 | 0.171                      |
| PRESS RATIO (T/T) 1.10   |                           |                            |
|  |                           |                            |
|  |                           |                            |
| REGEMERATOR DATA   |                           |                            |
| *********  |                           |                            |
| COLD SIDE HOT SIDE   |                           |                            |
| DELP 46.20 45.68   |                           |                            |
| DELT 210.01 -276.25  |                           |                            |
| AREA 0.40 1.52<br>FLOW 5.42 4.47   |                           |                            |
| FLOM 5.42 4.47 EFFECTIVENESS 0.36  |                           |                            |
| NTU 0.55   |                           |                            |
| CRATIO 0.76  |                           |                            |
| CMIN 15.85   |                           |                            |
| REGEN Q 4377.96  |                           |                            |
|  |                           |                            |

### TABLE 68. - FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 12.0

| ENGINE PERFORMANCE PARAMETER | s      |
|------------------------------|--------|
| *********************        | ****   |
| CHAMBER PRESSURE             | 1160.0 |
| VAC ENGINE THRUST            | 13474. |
| DEL. VAC. ISP                | 396.3  |
| TOTAL ENGINE FLOM RATE       | 34.0   |
| THROAT AREA                  | 5.547  |
| NOZZLE AREA RATIO            | 1000.0 |
| ENGINE MIXTURE RATIO         | 12.00  |
| CHAMBER/NOZZLE COOLANT DP    | 417.   |
| CHAMBER/NOZZLE COOLANT DT    | 793.   |
| ETA CH                       | 9.760  |
| CHAMBER/NOZZLE Q             | 7296.  |

| (  | CHAMBER/NOZZLE            | COOLANT                           | DP  | 417.             |                                |
|--|---------------------------|-----------------------------------|---|------------------|--------------------------------|
| (  | CHAMBER/NOZZLE            | COOLANT                           | DT  | 793.             |                                |
| E  | TA CH                     |                                   |   | 9.980            |                                |
| C  | CHAMBER/NOZZLE            | Q                                 |   | 7296.            |                                |
|  |                           |                                   |   |                  |                                |
|  |                           |                                   | CONDITIONS                                      |                  |                                |
|  |                           |                                   | **********                                      |                  |                                |
| STATION  |                           |                                   | ONDITIONS .                                     |                  | DENSITY                        |
| STATION<br>B.P. INLET  | PKE22                     | 37.4                              | 2.62  | ENTHALPY         | 4.37                           |
| 9 B EVIT   | 18.6<br>61.5              |                                   |   | -107.5<br>-104.7 | 4.37                           |
| DIMED TAN ET   |                           | 38.1<br>38.1                      | 2.62  | -104.7           | 4.37                           |
| IST STAGE EXIT   | 13524                     | 61.9                              |   | -9.1             | 4.23                           |
| 2ND STAGE EXIT   |                           | 84.1                              |   | 83.6             | 4.17                           |
| PUMP EXIT  | 3813.5                    |                                   |   | 173.9            | 4.16                           |
| COLD REGEN IN  | 3802.0                    | 105.5                             | 2.62  | 173.9            | 4.16                           |
| PUMP EXIT COLD REGEN IN COLD REGEN EX COOLANT INLET COOLANT EXIT TBV INLET TBV EXIT LOX TRB INLET LOX TRB EXIT H2 TRB EXIT H2 TRB DIFF | 3788.2                    | 105.5<br>642.8<br>642.8<br>1436.2 | 2.62  | 2243.4           | 0.98                           |
| COOLANT INLET  | 3788.2                    | 642.8                             | 2.62  | 2243.4           | 0.98                           |
| COOLANT EXIT   | 3371.4                    | 1436.2                            | 2.62  | 5031.2           | 0.41                           |
| TBV INLET  | 3351.4                    | 1436.4                            | 0.01  | 5031.2           | 0.41                           |
| TBV EXIT   | 2350.0                    | 1443.9                            | 0.01<br>0.01                                    | 5031.2           | 0.29                           |
| LOX TRB INLET  | 3351.4                    | 1436.4                            | 2.60  | 5031.2           | 0.41                           |
| LOX TRB EXIT   | 3146.7                    | 1420.6                            | 2.60<br>2.60                                    | 4969.8           | 0.39                           |
| H2 TRB INLET   | 3146.7                    | 1420.6                            | 2.60  | 4969.8           | 0.39                           |
| H2 TRB EXIT<br>H2 TRB DIFF<br>H2 BST TRB IN  | 2399.2                    | 1347.0                            | 2.60  | 4689.7           | 0.32                           |
| H2 TRB DIFF  | 2386.8<br>2378.7          |                                   |   | 4689.7           | 0.32                           |
| H2 BST TRB IN  | 2378.7                    | 1347.2                            | 2.60  | 4689.7           | 0.32                           |
| H2 BST TRB IN H2 BST TRB EXI H2 BST TRB DIF O2 BST TRB DIF O2 BST TRB DIF H2 TANK PRE GOX HEAT EXCH HOT REGEN IN HOT REGEN EX  | T 2371.0                  | 1346.4                            | 2.60  | 4686.9           | 0.32                           |
| H2 BST TRB DIF   | F 2365.7                  | 1346.5                            | 2.60  | 4686.9           | 0.32                           |
| OZ BST TRB IN  | 2357.9                    | 1346.5                            | 2.60  | 4686.9           | 0.31                           |
| OZ BST TRB EXI   | T 2354.3                  | 1346.1                            | 2.60  | 4685.3           | 0.31                           |
| OZ BST TRB DIF   | F 2353.8                  | 1346.1                            | 2.68  | 4685.3           | 0.31<br>0.31<br>0.0026<br>0.31 |
| H2 TANK PRE  | SS 18.6                   | 1364.6                            | 0.0015  | 4687.1           | 0.0026                         |
| GOX HEAT EXCH  | IN 2350.0                 | 1346.6                            | 2.60  |                  |                                |
| GOX HEAT EXCH  | 001 2346.6                | 1345.8                            | 2.60  | 4684.3           | 0.31                           |
| HOT REGEN EX   | 2346.6                    | 753.7                             | 2.60  | 4684.3<br>2604.1 | 0.31<br>0.54                   |
| AUI KEGEN EX   | 2326.5                    | 753.7                             |   | 2604.1           | 0.54                           |
| FSV INLET<br>FSV EXIT  | 2326.5                    | 760.4                             |   | 2604.1           | 0.29                           |
| FSV EXIT   | 1227.1<br>1218.7          | 760.4                             | 2.62  | 2604.1           | 0.29                           |
| CHAMBER  | 1160.0                    | 700.4                             | 2.02  | 2004.1           | V.L/                           |
| C - IDER   |                           |                                   |   |                  |                                |
|  | # OXYG                    | EN SYSTE                          | N CONDITIONS                                    |                  |                                |
| STATION  | PRESS<br>16.0<br>52.1     | TEMP                              | FLOW  | ENTHALPY         | DENSITY                        |
| B.P. INLET   | 16.0                      | 162.7                             | 31.44   | 61.9             | 70.99                          |
| B.P. EXIT  | 52.1                      | 164.9                             | 31.44   | 62.1             | 70.81                          |
| PUMP INLET   | 52.1                      | 164.9                             | 31.44   | 62.1             | 70.81                          |
| PUMP INLET<br>PUMP EXIT  | 1460.1                    | 172.1                             | 31.44<br>31.44<br>31.44                         | 67. L            | 71.04                          |
| 02 TANK PRES   | S 16.0                    | 400.0                             | 0.05  | 204.7            | 0.12                           |
| 02 TANK PRES   | 1437.7                    | 172.2                             | 2.72  | 67.1             | 71.00                          |
| POSV EXIT  | 1215.5                    | 173.0                             | 2.72  | 67.1             | 70.64                          |
| OCV INLET  | 1437.7                    | 172.2                             | 28.67   | 67.1             | 71.00                          |
| OCV EXIT   | 1352.4                    | 172.5                             | 2.72<br>2.72<br>28.67<br>28.67<br>2.72<br>28.67 | 67.1             | 70.86                          |
| PRIMARY INJ  | 1205.4                    | 173.0                             | 2.72  | 67.1             | 70.62                          |
| POSV EXIT OCV INLET OCV EXIT PRIMARY INJ SECONDARY INJ   | 1317.2                    | 172.6                             | 28.67   | 67.1             | 70.81                          |
| CHAMBER  | 1159.8                    |                                   |   |                  |                                |
|  |                           |                                   |   |                  |                                |
|  |                           | VE DATA                           |   |                  |                                |
|  |                           | ******                            | <b></b>   |                  |                                |
| VALVE  | DELTA P                   | AREA                              |   | % BYPASS         |                                |
| TBV  | 1001.                     | 0.001                             | 0.01  | 0.51             |                                |
| FSV  | DELTA P<br>1001.<br>1099. | 0.100                             |   |                  |                                |
| POSV   | 222.                      | 0.032                             | 2.72<br>28.67                                   |                  |                                |
| OCV  | 85.                       | 0.184                             | 28.67   |                  |                                |
|  | • • • • •                 | CTOR DATA                         |   |                  |                                |
|  |                           | .10R DAT                          |   |                  |                                |
|  |                           | • 0x                              |   |                  |                                |
|  |                           | - UA                              |   |                  |                                |

TABLE 68. — FULL-EXPANDER CYCLE WITH REGENERATION — O/F = 12.0 (CONTINUED)

|   |            |          | **************************************   |           |        |               |
|---|------------|----------|--|-----------|--------|---------------|
|   |            |          | *********                                |           |        |               |
| *********   | ******     |          | ****                                     | ******    |        |               |
| # H2 BOOST 1  | * SMIBRUT  |          | * H2                                     | BOOST PUR | 4P =   |               |
| ******  | ******     |          |  | ******    |        |               |
| EFFICIENCY  | 0.659      | •        | EFFICIEN                                 | CY        | 0.647  |               |
| HORSEPOHER  | 10.        |          | HORSEPON                                 | ER        | 10.    |               |
| SPEED (RPM)   | 28390.     |          | SPEED<br>S SPEED                         | (RPM)     | 28390. |               |
| MEAN DIA (IN)   | 1.34       | i        | S SPEED                                  |           | 2020.  |               |
| EFF AREA (1N2)  | 2.45       | •        | HEAD<br>DIA.                             | (FT)      | 1412.  |               |
| EFF AREA (1M2)<br>U/C (1DEAL)   | 0.485      | •        | DIA.                                     | (IN)      | 2.18   |               |
| MAX TIP SPEED   |            |          | TIP SPEE                                 |           | 270.   |               |
| STAGES  | 1.         |          | VOL. FLO                                 |           | 269.   |               |
| DELTA H (ACT)   | 2.82       | ?        | HEAD COE                                 | F         | 0.623  |               |
|   |            |          | FLOH COE                                 | F         | 0.144  |               |
| PRESS RATIO (T/   | 1.01       |          |  |           |        |               |
|   |            |          |  |           |        |               |
| *********   |            |          |  | ******    |        |               |
| # H2 TURBINE  |            |          |  | H2 PUMP   |        |               |
| *******   | * # *      |          | **                                       | ******    |        | CTACE THREE   |
|   | STAGE 1    | STAGE 2  | SI                                       |           |        | STAGE THREE   |
|   |            | *****    | 55510151011                              |           | 0.507  | 0.507         |
| EFFICIENCY  | 0.740      | 0.789    | EFFICIENCY                               | 0.585     | 0.573  | U.57/         |
| HORSEPOHER  | 1032.      | 1032.    | HORSEPOWER                               | 354.      | 343.   | 80450         |
| EFFICIENCY HORSEPOWER SPEED (RPM) MEAN DIA (IN) EFF AREA (IN2) U/C (IDEAL) MAX TIP SPEED DELITA H GAMMA (ACT) PRESS RATIO(T/T | 98658      | 98658.   | SPEED (RPM)                              | 78658.    | 78658. | 780>8.<br>646 |
| MEAN DIA (IN)   | 2.86       | 2.86     | S SPEED                                  | 545.      | 35/.   | 202.          |
| EFF AREA (1N2)  | 0.31       | 0.40     | HEAD (FT)                                | 43535     | 42///. | 417/6.        |
| U/C (IDEAL)   | 0.380      | 0.438    | DIA. (IN)                                | 3.44      | 5.44   | 3.44          |
| MAX TIP SPEED   | 1233.      | 1233.    | TIP SPEED                                | 1483.     | 1483.  | 1483.         |
| DELTA H   | 155.       | 125.     | VOL. FLOW                                | 278.      | 282.   | 282.          |
| GAMMA (ACT)   | 1.36       | 1.36     | HEAD COEF                                | 0.637     | 0.626  | 0.614         |
| PRESS RATIO(T/T   | 1.34       | 1.37     | FLOW COEF                                | 0.057     | 0.059  | 0.060         |
|   |            |          |  | *****     |        |               |
| **********  |            |          |  | BOOST PU  |        |               |
| # 02 BOOST  |            |          |  | *****     |        |               |
| *********   |            |          |  |           | 0.715  |               |
| EFFICIENCY<br>HORSEPOHER  | 0.798      |          | EFFICIEN<br>HORSEPON<br>SPEED<br>S SPEED | IC 1      | 4.713  |               |
| HORSEPOMER  | 6.         |          | HUKSERUM                                 | (DDM)     | 0579   |               |
| SPEED (RPM)<br>MEAN DIA (IN)  | 8579.      |          | SAFER                                    | (Krm)     | 2919   |               |
| MEAN DIA (IN)   | 3.69       | <u>'</u> | 2 SPEED                                  | (57)      | 74.    |               |
| EFF AREA (IN2)<br>U/C (IDEAL)   | 3.60       | )        | HEAD<br>DIA.                             | (11)      | 2.44   |               |
| U/C (IDEAL)   | 0.514      | •        | DIA.                                     | (141)     | 91.    |               |
| MAX TIP SPEED   | 178        |          | TIP SPEE                                 | .U        | 199.   |               |
| STAGES  | 1.         | _        | VOL. FLO                                 | -         | 0.283  |               |
| DELTA H (ACT)   | 1.60       |          | HEAD COE<br>FLOW COE                     | .r<br>-   | 0.253  |               |
| GAMMA PRESS RATIO (T/   |            |          | FLUM CUC                                 | ,г        | 0.253  |               |
| PRESS RATIO (17   | 1.00       | ,        |  |           |        |               |
| ********  |            |          | ***                                      | *******   |        |               |
| # 02 TURBIN   |            |          | * 0                                      | 2 PUMP .  |        |               |
|   |            |          |  | *******   |        |               |
| EFFICIENCY<br>HORSEPOHER<br>SPEED (RPM)   | 0.696      | 1        | #FFICIEN                                 | ICY       | 0.721  |               |
| FLLTCTEIACL   | 226        | •        | HORSEPON                                 | FR.       | 226.   |               |
| SPEED (RPM)   | 58806      |          | EFFICIEN<br>HORSEPON<br>SPEED            | (RPM)     | 58806. |               |
| MEAN DIA (IN)   | 2.86       | -<br>5   | S SPEED                                  | •         | 2123.  |               |
|   |            |          |  |           | 2854.  |               |
| EFF AREA (IN2)<br>U/C (IDEAL)<br>MAX TIP SPEED  | 0.349      | •        | HEAD<br>DIA.                             | (IN)      | 1.93   |               |
| MAX TIP SPEED   | 735        |          | TIP SPEE                                 | D         | 496.   |               |
| STAGES  | 1          |          | VOL. FLO                                 | ж         | 199.   |               |
| DELTA H (ACT)   | 61.39      | 9        | HEAD COE                                 |           | 0.373  |               |
| GAHHA   | 1.30       |          | FLOW COE                                 |           | 0.177  |               |
| PRESS RATIO (T/   |            | _        |  |           |        |               |
|   |            |          |  |           |        |               |
|   |            |          |  |           |        |               |
|   |            |          |  |           |        |               |
| 1   | REGENERATO | OR DATA  |  |           |        |               |
|   | *******    | *****    |  |           |        |               |
| COLD  | SIDE +     | HOT SIDE |  |           |        |               |
| DELP 1  | 3.85       | 20.11    |  |           |        |               |
|   | 7.32       | -592.10  |  |           |        |               |
|   | 0.40       | 1.52.    |  |           |        |               |
|   | 2.62       | 2.60     |  |           |        |               |
| EFFECTIVENESS   | 0.4        | 48       |  |           |        |               |
| NTU   | 0.         | 96       |  |           |        |               |
| CRATIO  | 0.         |          |  |           |        |               |
| CHIN  | 9.         |          |  |           |        |               |
| REGEN O   | 5415.      |          |  |           |        |               |
|   |            |          |  |           |        |               |

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| Emphasis was placed on de                           | fining requirements for high-per   | formance engines capable                             | of achieving reliable and versatile      |
| operation in a space enviro                         | onment. Four variations on the   | e expander cycle were con                            | mpared, and the advantages and           |
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| 7,500 to 50,000 to till ust all                     | d a wide range of chamber pres   | sure and nozzie expansion                            | ratio.                                   |
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